

April 2013

Motorsports Safety

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Motorsports Safety

A Major Qualifying Project Proposal
submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

Anthony Begins

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April 24, 2013

Approved by:



Professor Allen H. Hoffman, Advisor

Abstract

The prevalence of neck injuries and basilar skull fractures in motorsports has caused many sanctioning bodies in top-tier auto-racing divisions to mandate the use of head and neck restraints. Case studies have shown that the most common restraint has inhibited drivers from exiting the car in emergencies, such as a fire, as it can become entangled in the window nets, roll cages, or the ground depending on the orientation of the car. Generally, this entanglement occurs due to the inability to remove the device while wearing a standard racing helmet. The goal of this project was to design and prototype a new head and neck restraint that would be able to be removed easily while wearing a helmet hereby facilitating exiting a car in an emergency. Several preliminary designs were evaluated. The final prototyped design that was shaped similar to the standard head and neck restraints incorporated two lateral sliding pin joints each with one degree of freedom that permitted the removal the wings. Quick release latches prevent movement of the wings while in use. The computer aided design program Creo was utilized to model the device and to perform a stress analysis using forces associated with accelerations of high-speed crashes. Then, a group of 11 people evaluated the prototype by performing a set of tests that involved removing the device like a traditional head and neck restraint and removing the device by releasing a wing via one of the quick releases. Time data were collected for both tests, and a matched pair t-test was performed using a P-value of .05 to compare the times. The result from the test showed that the data were statistically significant signifying that it takes less time to remove the device using one of the quick release latches. The prototype was successfully tested, and the proof of concept was demonstrated. A second-generation prototype should address the issues of reducing the total weight, implementing a different latch mechanism, and improving the overall aesthetics.

Acknowledgements

This Major Qualifying Project team would like to express their gratitude toward the advisor Professor Allen Hoffman for his guidance throughout the project. The team would also like to recognize Jean Paul Cyr, Ray Dona, and David Rodman for their input and suggestions regarding the first generation prototype and future iterations.

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1. Introduction

Motorsports is a group of sports that involve the use of motorized vehicles primarily for racing purposes. The entire category of motorsports includes vehicles that travel by land, air, and water; however, the most popular subset of motorsports is automobile racing, or auto racing. Within the subset, there are many divisions, which differ from each other based on the class of car being raced. Due to the advancement in technology and equipment over the years, official sets of regulations have been formulated for all divisions of racing to ensure neutrality amongst the drivers. These are strictly enforced by professional sanctioning bodies, such as National Association of Stock Car Auto Racing (NASCAR) for stock car racing, Sports Car Club of America (SCCA) for formula car racing, National Hot Rod Association (NHRA) for drag racing, and Fédération Internationale de l'Automobile (FIA) for racing in general (Sanctioning Bodies).

With some racecars traveling at speeds over 200 miles per hour, the probability of crashes in motorsports increases under the driving conditions in a racing competition; this simultaneously elevates the possibility of drivers acquiring life threatening injuries depending on the severity of the situation. As a result, the previously mentioned organizations established standards regarding safety in attempt to reduce and prevent injuries from frontal, side, and posterior impact crashes during competition. Some of the instituted regulations incorporated the mandatory usage of restraint belts and helmets. Although these devices have proven to be successful in the sense they have saved many lives, drivers still acquired serious injuries in the neck and head region ranging from sprains to basilar skull fractures. The primary cause of these injuries in crashes is the forward movement of the head and neck on impact while the seat and belts protect the rest of the body. Due to the unpredictability of crashes in racing, protection for the head and neck was not required for drivers in various divisions. However, after several

deaths of well-known drivers in 2001, the use of head and neck restraints was mandated to reduce extreme motion of the head that causes fatal injuries (Ryan, 2000; Teng, 2004).

Since the mandating of head and neck restraints, several companies have designed and manufactured devices that are certified for use in various racing divisions. However, the HANS device, or the Head and Neck Support device, has shown the most promise in the world of motorsports as it is the most accepted device by professional drivers. The reason for its popularity is due to the SFI Foundation, originally known as the SEMA Foundation Inc., which is a non-profit organization established to issue and administer standards for performance automotive and racing equipment. According to SFI Specification 38.1, which can be seen in Appendix A, the HANS device meets all of the necessary criteria for head and neck restraints making it an effective device in terms of the standards (SFI Website). Although it successfully reduces the movement of the head and neck at the point of impact in crashes, there are various problems related to this device. One of the more egregious problems includes the difficulty related to exiting the car while wearing a HANS device in an emergency, such as a fire or a situation where emergency medical personnel need to place a neck brace on a severely injured driver. The other significant problem that drivers have encountered is the inability to remove the device while wearing a standard helmet. Since it is bulky and rigid, the HANS device can easily become entangled with the car's accessories further inhibiting quick escape from dangerous situations. Therefore, the overall goal of this Major Qualifying Project is to design, analyze, manufacture, and evaluate a head and neck restraint that can be easily removed while wearing a standard racing helmet to ease the process of exiting the car in the case of a frontal crash or fire.

2. Background Research

To attain a clarified scope of the problem, extensive background research is necessary to understand the methods of safety already in use today. In addition to head and neck restraints, several other devices are used in conjunction with them, such as racing harnesses and standard racing helmets. Additionally, product and patent research of devices on the market will show how these devices may meet the criteria for the needs of the driver in common competition situations. Investigation of case studies and capabilities of current devices on the market can reveal any underlying issues.

2.1. Original Safety Devices

Prior to the mandating of head and neck restraints, the primary safety devices used in racing competitions were safety harnesses and helmets. Since the implementation of these devices into the racing world, there have been several different moderations and versions used in current practices. These devices are described in the following sections.

2.1.1. Safety Harnesses

Safety harnesses in auto racing have evolved far beyond the standard three-point seat belts installed in the everyday passenger car. Figure 1 displays the typical three-point safety harness. These harnesses feature at least one retractable point and ratcheting straps to aid the drivers in fastening and releasing their belts on a daily basis. However, racing safety harnesses feature fixed point mounting at every location, and are required to be mounted to a roll bar, on the frame of the car, or at a reinforced mounting point. Like many other devices in auto racing, safety harnesses must conform to an SFI-Rating to be legal for use in many divisions. As the

webbing of the seat belt begins to degrade and weaken, SFI-ratings specify that replacement be required every two years to ensure that the safety harness can function to its greatest potential (Industrial Seat Belt).



Figure 1. Three-Point Seat Belt (About Snell)

Safety harnesses come in various sizes and include different numbers of mounting points. The size of the harness is determined by the width of the belt used, which the typical widths range from about 1.875" to 3". The necessary width depends on the division of racing, as the sanctioning bodies require different widths for different categories of car. Additionally, there are different numbers of mounting points. While passenger car belts have evolved from a simple two-point, lap belt system to a three-point shoulder and lap belt system, current racecar safety belts include several mounting points, including four-point, five-point, and six-point harnesses.

2.1.1.1. Four-Point Harness



Figure 2. Four-Point Harness (Racing Gear Buyers)

The four-point mount safety harness, depicted in Figure 2, is a type of harness, which has a two-point lap belt combined with two shoulder belts. They meet in the center with a quick release latch allowing the driver to disconnect all of the belts at once and exit the car. This type of harness is discouraged and often illegal to be used in competition in many divisions as it does not feature an anti-submarine belt. The anti-submarine belt prevents the driver from sliding out from under the shoulder belts and lower in the seat in the event of an impact. Without this, the driver risks fractured ribs, asphyxiation, or a broken neck from the shoulder belts as there is nothing to prevent the driver from sliding down under the belts (Racing Gear Buyers).

2.1.1.2. Five-Point Harness

The five-point harness is essentially the same as the four-point harness; however, an anti-submarine belt, or ‘crotch belt,’ is added to the system and is mounted between the driver’s legs. This additional feature prevents the driver from plunging below the shoulder belts. This type of harness is widely accepted by sanctioning bodies and is used in a variety of applications. A quick release is also featured in this system utilized to allow for an easy exit of the car (Racing Gear Buyers).

2.1.1.3. Six-Point and Seven-Point Harnesses

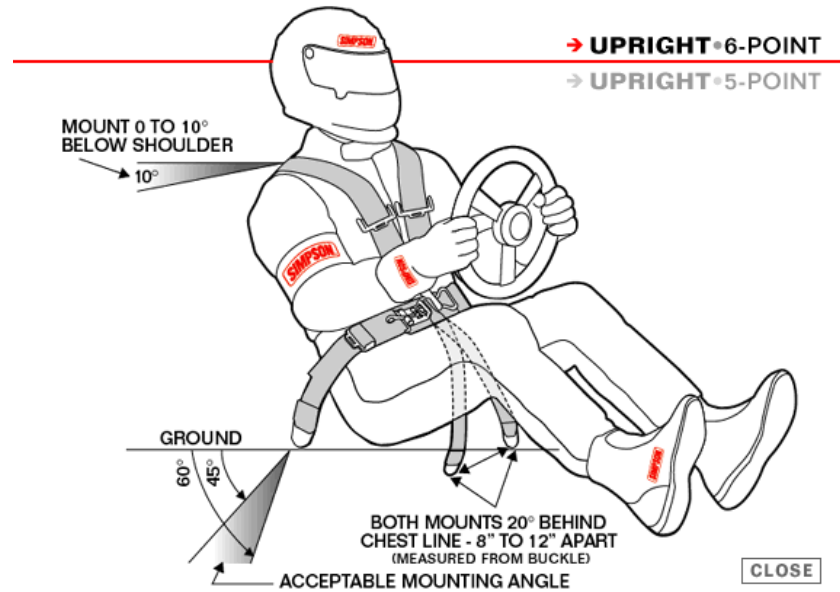


Figure 3. Six-point harness diagram (Seating Positions)

The six-point harness, depicted in Figure 3, is a five-point harness modified to have two anti-submarine belts, which connect to the main latch between the driver's legs; however, these belts separate underneath the driver's legs. This design is meant to increase the comfort and to distribute the load if the driver incurs an impact. A sanctioning body may require the use of a six-point harness; however, it is sometimes required for use in only extreme situations. For instance, the Formula SAE division mandates "cars with a reclined driving position (a seat back angled at more than thirty degrees [30°] from the vertical) must have either a six-point or seven-point harness, AND have either anti-submarine belts with "quick adjusters," or have two (2) sets of antisubmarine belts installed." This clause suggests that six-point or seven-point harnesses be used only under specific conditions to ensure a higher level of safety during a competition.



Figure 4. Seven-point racing harness (Getting Belted, 2009)

A seven-point harness shown in Figure 4 is five-point combined with a six-point as it features the two shoulder belts, two lap belts, and three anti-submarine belts. This final belt is considered a “negative G belt” (Simpson Racing).

2.1.2. Safety Helmets

In auto racing, the type of helmet required can vary from division to division as each division involves different speeds and dangers, which can require different levels of safety. In general, there are two distinct types of helmets on the market: DOT and Snell rated helmets.

2.1.2.1. DOT-Rated Helmets

DOT rated helmets, or “Department of Transportation,” are typically only used for highway use. These helmets meet the requirements set forth by the Department of Transportation. Generally, these helmets are only used by motorcycle riders, and most often solely for street and highway use. However, some “lower” or entry-level racing divisions, typically local divisions, will allow a DOT helmet for use in some of races. These helmets are not allowed for use in high level racing, such as NHRA, NASCAR or other governed and sanctioned divisions.

2.1.2.2. Snell-Rated Helmets

Snell-rated helmets are helmets that have met the requirements set by the Snell Foundation. The Snell Foundation was created after William Snell died in a racing event in 1956 when his then state-of-the-art helmet failed to protect him. The Snell Foundation provides requirements to aid in the classification and standardization of racing helmets as a means to improve the overall level of safety. In general, the helmets are classified by year and type.

2.1.2.2.1. Year Rating

Each helmet produced that meets the Snell standards is denoted by a year and a letter classification. The year classification denotes what year standard the helmet meets and for how long the helmet will be accepted for use in competition. For instance, there are SA2000, SA2005 and SA2010 helmet classifications. Simply stated, a “good rule of thumb” is that a helmet should only be usable for 12 years past the date of the given standard. For instance, a SA2000 helmet will be phased out at the beginning of the year 2012.

2.1.2.2.2. Motorcycle Standard

The Motorcycle standard or M helmet is used for motorcycle competitions. This type of helmet does not have roll-bar or roll cage protection standards; however, it does have a larger view port. The M-standard helmet also does not have fire-protection ratings. This type of helmet is generally only used for motorcycle racing and some auto racing.

2.1.2.2.3. Special Application-Standard

Special Application, or SA-Rated, helmets are intended for use in auto racing. The SA standard does feature fire protection levels along with roll bar or roll cage impact protection. This type of helmet is largely accepted for auto racing, as the SA fire rating is instrumental in helmet safety (About Snell).

2.1.2.2.4. SAH Standard

Not all helmets are equipped to be used with a neck and neck restraint like the HANS device. In fact, most have to be retrofitted with anchors by drilling and inserting the proper hardware. However, with the popularity of the HANS device in recent years, manufacturers have been offering helmets that are ready for use with the HANS device. The SAH rating allows the consumer to purchase a helmet with the anchors already drilled and inserted into the helmet. Not only will they be installed, but also the helmet is backed by Snell ratings, which cover the safety of the anchors, as well as the rating set for by the SA standard (About Snell, SA Helmets vs. SAH).

2.2. Head and Neck Support (HANS) Device

2.2.1. Ideation

In the early 1980s, two friends, Bob Hubbard and Jim Downing, discussed methods of improving safety in motorsports after a mutual friend died from a basilar skull fracture during a race. Through the recognition of the number of injuries resulting from a restrained torso and an unrestrained head, both decided it would be advantageous to design a system that would protect drivers from acquiring these injuries. Considering Hubbard had extensive experience as a biomechanical crash engineer, he applied his prior knowledge to develop a basic solution, which was to design a piece of equipment that would move with the torso but restrain the head in relationship to the body. In 1984, Hubbard generated the first HANS, Head and Neck Support, Device, which fit over the shoulders and attached to the helmet. Figure 5 shows the first generation of the HANS Device connected to the standard helmet (HANS Safety Timeline).



Figure 5. Model 1 HANS Device (Ryan, 2000)

As a driver of an IMSA sports car, Downing offered to test the product; however, the full capabilities of the device could not be determined as he did not crash often. In 1989, initial tests were conducted at Wayne State University using crash sleds and safety dummies to observe the effectiveness of the HANS device. The results of the crash tests demonstrated that the amount of stress on the head and neck of the “driver” was reduced by about 20% when using a HANS device. Figure 6 shows results from a crash test with and without the device. The schematic demonstrates that the usage of a HANS device clearly reduces the overall movement of the head and neck in addition to the forces exerted on the driver’s body (Ryan, 2000).

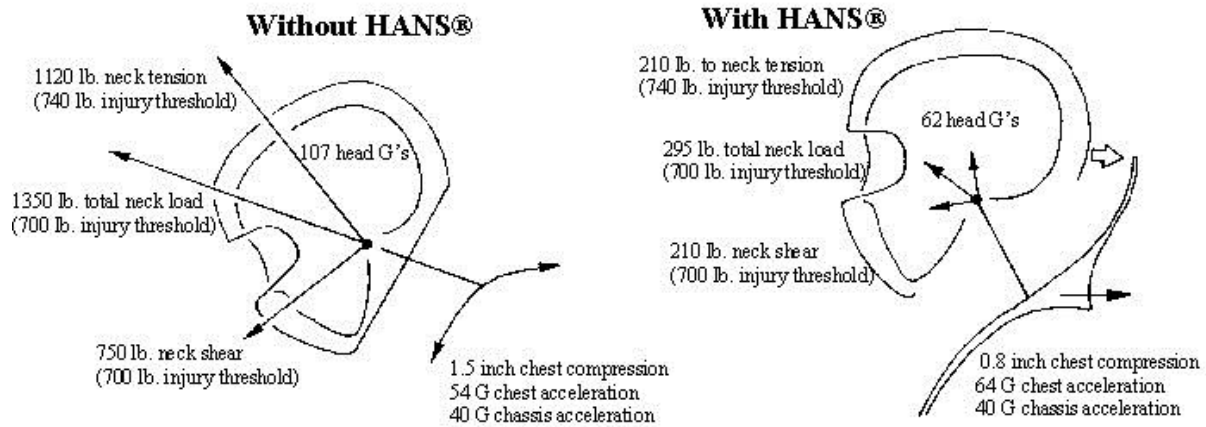


Figure 6. Crash Test Results Diagram depicting Forces in a Crash with and without the HANS Device (Ryan, 2000)

In 1987, Hubbard received a US Patent for the HANS device. After receiving the patent, both Hubbard and Downing presented their safety product to various companies including Simpson and Bell. Although both companies were interested in the HANS device, neither found the head and neck restraint marketable. As a result, Hubbard and Downing formed their own company Hubbard Downing Incorporated in 1991, so they could manufacture, sell, and promote the HANS device themselves. Ten years later, NASCAR mandated the use of head and neck restraints for Cup drivers after the deaths of Adam Petty, Kenny Irwin, and Dale Earnhardt Sr. (Ryan, 2000).

2.2.2. Current HANS Device

Since its conception in the 1980s, the HANS device has become one of the most widely recognized and accepted head and neck restraint systems in racing series. The HANS device is composed of carbon fiber that is processed using different methods depending on the given series. The Professional Series, which is the most expensive version, is made of hand laid, high modulus carbon fiber, which is extremely light, making the total weight only one pound. The Extra Series HANS device involves the usage of traditional hand laid carbon fiber. Designed for inexperienced drivers, the Sport Series in Figure 7 is constructed of carbon fiber that is produced

by injection molding. This process generates carbon fiber of a higher weight, which increases the overall weight of the device to 2.25 pounds (HANS Device Revolutionizing).



Figure 7. HANS Model 20, Sport II (HANS Device Revolutionizing)

The HANS device incorporates a series of tethers to attach it to the helmet in an effort to limit the movement of the driver's helmet in the event of a crash. The device itself is anchored to the driver's body by routing the racing harness over the device. One model of the HANS device features adjustable "wings" for the harness to rest on, making it easier to use by drivers of various heights and sizes.

The HANS device attaches to the helmet using anchor posts, depicted in Figure 8, which can be installed on the helmet by either the user or a HANS dealer, or the helmet can be ordered already equipped with anchors direct from helmet manufacturer.

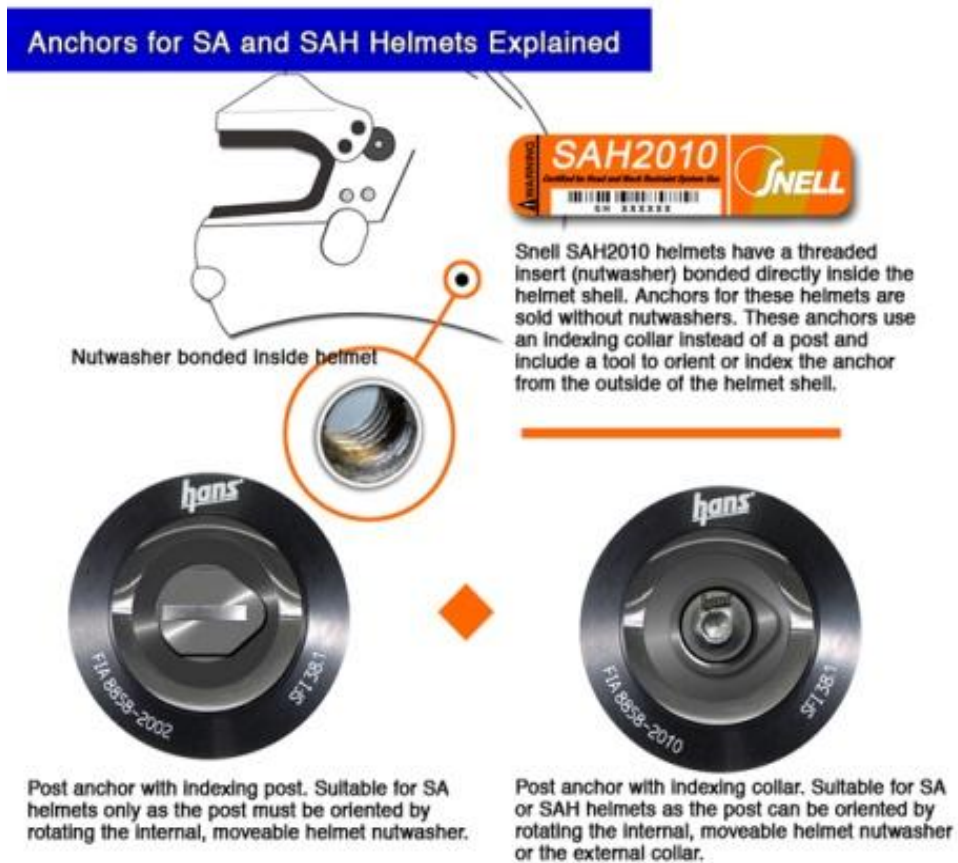


Figure 8. Mounting Anchors for the HANS Device (HANS SAH)

In 2008, the HANS device began using a sliding tether system. The tethers were originally fixed to the back of the device; however, this limited the motion of the driver when they attempted to turn their head while inside the cockpit of the racecar. The sliding tether system allows the tethers to move along the back of the device enabling a “full range of vision for all drivers” (HANS Device Revolutionizing).

2.3. Recognized Problems with the HANS Device

Even though the HANS device is the most used head and neck restraint in the top racing divisions, professional drivers have noted problems with device through personal experiences. The two main problems that have been mentioned about the HANS device include that it makes exiting the car difficult in an emergency and removing it is nearly impossible when entrapped in the vehicle. The subsequent sections include case studies that involve professional drivers experiencing problems related to the HANS device.

2.3.1. Jeff Altenburg: World-Challenge Series

In 2006, Jeff Altenburg's World-Challenge car caught fire during a race. While wearing a HANS device, Altenburg had to exit his vehicle, which is displayed in Figure 9.



Figure 9. Jeff Altenburg's World-Challenge Series Car (Puerto Rico, 2003)

In a statement made about the race, Altenburg describes his difficulties exiting the car while wearing the HANS device:

"When the fire started, it was outside the driver's side of the car and I had to exit through it. My HANS snagged on the window net for a moment...The extreme heat of the fire led me to drop and roll since the heat may have been burning fuel on my suit. Luckily, that wasn't the case. The fire crews put the fire out quickly, and the car was not damaged more than cosmetically."

If the window net had not melted, Altenburg would have continued to struggle within the car while awaiting the rescue crews to arrive, putting his life in danger (Puerto Rico, 2003).

2.3.2. Sam Hornish: Indy Racing League

During the 2005 Indianapolis 500 practice, Paul Dana spun out of control and hit the outside retaining wall leaving a debris-covered track behind him. Sam Hornish, the driver of the Penske Toyota in Figure 10 was in the proximity of Dana and hit one of the many pieces of debris. After the impact, Hornish's car landed upside-down and slid across the racing surface.



Figure 10. Sam Hornish's Car seen Upside-Down (Spectacular Indy Crashes, 2005)

Eventually, Hornish's car came to rest right side up in the central grass section in the arena. Although the car was not on fire, his exit from the non-closed cockpit car was far from easy. As noted by Motorsport.com, Hornish struggled to free himself from the wreckage. His comment was:

“...I...kind of braced myself because I've heard stories of people letting themselves go when the belts (release), so I just put one hand down, turned the other one (belt lock) and started crawling out. The safety guys were there. I was unbuckled and starting to come out, but my HANS device, when I was trying to get out, kept getting stuck in the grass so I had to have them help me take that off. It was interesting... (My helmet) wasn't on the

ground at all. The roll hoop bent a little bit but it was fully intact, but it was good as far as that goes."

Despite the mandatory roll hoop put in place behind the open cockpit of the IRL car, the exit from his car was impeded by his HANS device. The HANS continued to get stuck on the ground causing difficulties for Hornish to exit the car in a timely fashion. Had the car been on fire, Hornish would have been trapped in the car, helplessly awaiting crews to come to his rescue (IRL: Indy 500, 2005).

2.3.3. Rusty Wallace: NASCAR Sprint Cup Series

While the above cases are instances where the driver struggled to exit a vehicle in an emergency or after a crash, these are not the only cases. Rusty Wallace, a former NASCAR Sprint Cup Champion, had issues adjusting to the use of the HANS. He mentioned that he did not feel comfortable while wearing the device. Although the driver's comfort is important, the main, underlying issue with the HANS device is exiting the car. NASCAR.com reports that, "another problem was the placement of Wallace's seat. Installation of the HANS pushed the seat forward to ensure clearance for a roll bar behind Wallace's head. But moving the seat forward cut down on side window space, critical for Wallace's ability to get quickly out of the car in an emergency" (Montgomery, 2005).

2.4. Other Head and Neck Restraints

Examination of the other head and neck restraints on the market is useful to visualize the other methods companies have used to solve the same problem. Some of the other devices include the DefNder, the Isaac System, the NecksGen, and various Simpson Racing Products.

2.4.1. DefNder

The DefNder features the same general design as the HANS device with its sliding tethers, quick releases, and anchors for the helmet. The device is made with “injection molded Dupont Nylon Composite,” which yields an overall weight of 2.6 pounds. The tethers are made using a Kevlar material in an effort to create a fire resistant tether. Figure 11 depicts the DefNder Head and Neck Restraint.



Figure 11. DefNder Head and Neck Restraint (DefNder)

The DefNder was marketed more towards the ‘weekend racer’ as opposed to a professional driver as they offered complementary patches, shirts, stickers and hats with the purchase of one of their devices while competitors did not. Although it was certified as a useable device in competition, the Defnder is no longer being produced due to a lawsuit filed against them by HANS for a patent violation (DefNder).

2.4.2. Isaac System

The Isaac device, named after Sir Isaac Newton, is one head and neck restraint unlike any other device on the market due to its fundamental design. The Isaac device does not feature a wraparound shell that surrounds the back of the driver's neck, but features two dashpots that link to the helmet via bolts and a quick release pin. Figure 12 displays the Isaac's dashpot system.



Figure 12. the Isaac's Dashpot System (Isaac)

These dashpots return to a connector, where the shoulder belts rest. These resemble the connectors that ordinary three-point safety belts used in non-racing vehicles loop through for their latching mechanism, which is depicted in Figure 13.



Figure 13. Isaac Restraint Device with the Seatbelt Loop (Isaac)

The Isaac comes in several models including the Isaac Link, Intermediate Isaac, Titanium Isaac, Kids! Isaac, and the Quarter Midget Isaac that differ based on price and utilized materials. The most basic model, the Isaac Link, features aluminum mounting mechanisms along with “certified mil spec parachute webbing...in place of the damper assembly to reduce costs.” This device costs \$199 making it the least expensive device on the market. At the other end of the cost spectrum is the Titanium Isaac, which features titanium alloy structures alongside the

aforementioned dashpots. Given the implementation of titanium, this model costs \$3,250, which is the most expensive device on the market.

Although there are appealing characteristics of this device, there has been criticism regarding the Isaac System as they are not SFI certified. Isaac Systems provides this response on their website: "...Isaac® systems are *not* 'SFI certified'. Why? Because SFI Specification 38.1 contains a section that excludes only the Isaac® system. Specifically, section 2.5 states:

"Adjustment and release mechanism(s) shall be accessible to both the user and to external personnel such that no additional motion is required, other than the release of the seat belt, to disengage the Head and Neck Restraint System during emergency situations.

Because the Isaac® design keeps the belts on the shoulders and reduces lateral head torque by connecting the helmet to the shoulder belts, it does not comply with this section of SFI Spec 38...Every time a head and neck restraint has trapped a driver in a car it has been an SFI-type design--not sometime, not most of the time, *every* time. This danger is avoided with the Isaac® system because it is disconnected and left in the car every time the driver exits, so it becomes second nature."

Due to the lack of certification, this product is not used frequently amongst professional drivers (Isaac).

2.4.3. NecksGen

The NecksGen device, pictured in Figure 14, which is produced in California, follows the same general layout of the HANS and the Defnder.



Figure 14. NecksGen Device (NecksGen)

The NecksGen features a wraparound design with a tether mounting point behind the helmet. The tethers are fixed unlike those of the Defnder and the HANS. To enable quick removal of the device, the NecksGen has quick releases along with an emergency release tab. Additionally, this head and neck restraint comes supplied with all of the necessary equipment for proper connection to the helmet. Unlike the Isaac, it can be easily attached to any SAH2010 style helmet, as such helmets come equipped with the pre-drilled mounting holes. The NecksGen is made of Dupont carbon fiber, weighs in 1.6 pounds, and costs \$599. The manufacturers of NecksGen claim that the device has a level of flexibility making it more comfortable than other devices. Lastly, this device is SFI certified making its usage legal in many racing divisions (NecksGen).

2.4.4. Simpson Head and Neck Restraints

The Simpson head and neck restraints combine the back section of the HANS, DeFender and NecksGen to use as a mount for various tethers, but they do not feature the same “wings” in which the device is secured to the user via the restraint belts. Simpson utilizes a “patented Seatbelt Anchor System,” which straps the device directly to the user rather than using the racecar’s harness to secure the device to the driver. An example of Simpson’s version is depicted in Figure 15.



Figure 15. Simpson Hybrid Pro Rage (Simpson Racing)

Simpson offers five different models: the Hybrid Pro, Hybrid Pro Rage, Hybrid, Hybrid X and R3. The major difference among the models is simply the arrangement of the belts on the device to provide the user with different levels of safety and comfort. The Hybrid Pro Rage, starts at \$595 pricewise, features sliding tethers, includes materials of both carbon fiber and composites, and is SFI 38.1 certified. On the upper end of the spectrum, the Hybrid X, which is also SFI certified, provides the highest level of safety among the Simpson products. It is made of carbon fiber like most head and neck restraints and includes six tethers. While the Pro Rage and the Hybrid X are the lower and upper ends of the spectrum, the other models have their own selling points. The Hybrid Pro is not only compliant with SFI’s specifications, but it also is

NASCAR approved, making it one of only two devices allowed in NASCAR competition. The Simpson Hybrid is compliant with the FIA 8858-2010, which stands for Federation Internationale de l'Automobile, allowing the device to be used in international divisions as well as divisions that require FIA certification (Simpson Racing).

2.4.5. Summary of Available Head and Neck Restraints

Table 1 summarizes the information on head and neck restraints that are available for use around the world. The table can be used to compare the devices based on their price, weight, certification, structure, and materials.

Table 1. Comparison of Available Head and Neck Restraints

	DefNder 	HANS 	Issac 	NecksGen 	Simpson 
Price	\$549	\$445-\$995+	\$199-\$3,250	\$599	\$595-\$1195
Weight	2.6 lbs	1-2lbs	-	1.6 lbs	-
SFI 38.1 Compliant?	YES	YES	NO	YES	YES
Structure	Sliding Tethers with shoulder wings	Sliding Tethers with shoulder wings	Dashpot (or tethers) on sliding seatbelt mount	Fixed tethers with shoulder wings	Seatbelt anchors system with fixed tethers
Material	Dupont Nylon Composite and Kevlar	Dupont Polymer or Carbon Fiber	Dashpot & Aluminum or Titanium	Dupont Carbon fiber composite	Carbon fiber and composites

2.5. Existing Patents on Head and Neck Restraints

In addition to examining current products on the market to assist in ideation, patent research is quite helpful identifying additional concepts that may not have been commercialized. The researched patents includes products all affiliated with Simpson Performance Products as they purchased the company Safety Solutions, and as of September 27, 2012, they bought HANS Performance Products (Simpson Racing).

2.5.1: Patent Number US 6931669 B2

Patent Number 20050015858A1 was issued on January 27, 2005 to Trevor Ashline for his invention of a head restraint device with a back member for a driver operating a high performance vehicle (Figure 16). Along with the back member, the device consists of various straps as a means of securing it to the driver. The first strap, annotated as 12, attaches the back member, which is positioned on the driver's back, to the base of the driver's helmet. The second strap, annotated as 20, on the device is a releasable strap that encircles the driver's torso as a form of securement. With a release mechanism in the front, the driver should be able to remove the device quickly in the case of an emergency. The last set of straps, 30 in the diagram, is designed for the securing of the device to the driver's shoulders.

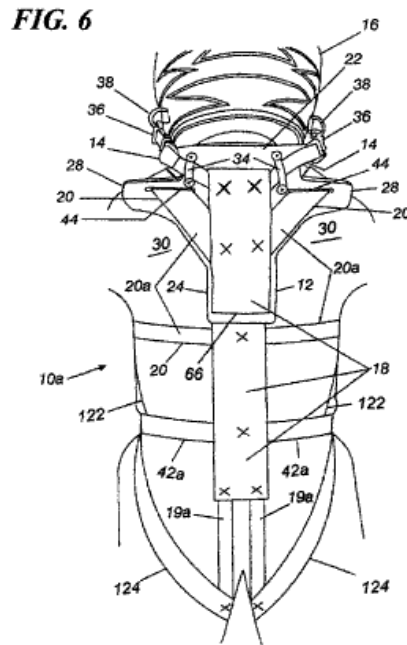


Figure 17. Patent Number 7765623: Head and Neck Restraint with Spacer on the Back (Ashline, 2012)

Another major difference is that this device straps directly to the user, unlike the HANS, which rests on the driver's shoulders under the safety belts. The device does have lateral extensions (28 in Figure 17) where the belts rest; however, this is not the primary means of attachment. An additional feature of this device is a harness that straps the device to the user, which intricately weaves through the main structure. Also, there is a slot in the "spacer" where a strap passes through (18 in Figure 17); this strap is known as the anchor strap. Finally, the device includes straps which wrap around the drivers torso (42a), around and through the legs (124 and 19a), and attach at the users back. These straps enable the driver's body to act as an anchor (Ashline, 2012).

2.5.3. Patent Number 6499149

This patent was issued to Trevor Ashline of Safety Solutions on December 31, 2002 for a head and neck restraint that consisted of tethers attaching to the driver and the helmet. This series of tethers allows the driver to exit the car quickly without have a large “bulkhead” or “spacer”, like other designs, which would inhibit the exiting of the racecar.

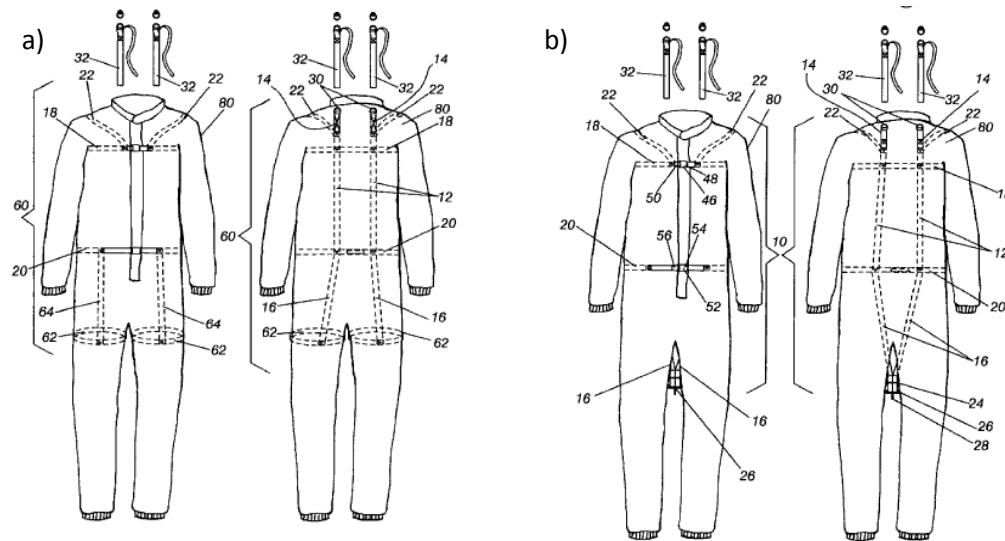


Figure 18. Patent Number 6499149: Figure 18a. Device with Anchors around the Legs. Figure 18b. Device with Anchor Strap between the Legs (Ashline, 2002)

This design includes the concept of having at least one anchor strap; however, it comes with anchors located at various positions on the device: along the back of the driver (12 in Figure 18), another between their legs, attachments to the helmet (32 in Figure 18), and to the seatbelts, a chest strap, a waist strap and leg straps (62 and 64 in Figure 18a). This device also features quick releases on the helmet and seatbelt attachments to aid in the driver’s ability to exit the car quickly (Ashline, 2002).

2.5.4. Patent Number US 2008/0256684 A1

This patent was filed in 2008 by Trevor Ashline of Safety Solutions for a head and neck restraint utilizing a main support member and a series of tethers. This device features tethers on the sides, rather than the back, as seen in the HANS device. It retains the concept of a main back support, where tethers can be attached.

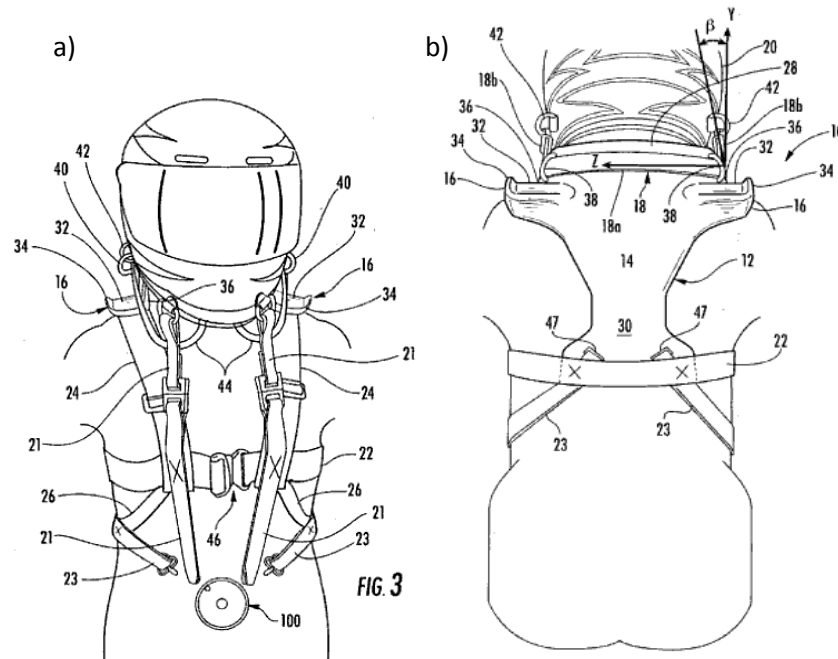


Figure 19: Patent Number US 2008/0256684 A1: Figure 19a. Front View. Figure 19b. Back View (Ashline, 2008)

The tethers mount to the side and front of the helmet using D-shaped rings and quick releases. The device's unique main concept is that it connects to the driver's safety harness at point 10 depicted in Figure 19a. This method of attachment causes the seat belts and the driver to act as anchors. Finally, the product features waist, torso, shoulder and two “anti-submarine” belts, which pass under and between the driver's legs to connect (100 in Figure 19a) at a single point (Ashline, 2008).

2.5.5. Patent Number 6813782

This patent was issued to Harry Klintzi on November 9, 2004 for a head and neck restraint that utilizes a system of tethers; this device is depicted in Figure 20. Essentially, this design eliminates the need for a rigid structure or component, which typically acts as a point of attachment for the tethers. In this case, however, the tethers attach directly to both sides of the helmet (42, 46) and on the back of the helmet (44). These tethers or straps are affixed to the suit

permanently and can be attached inside, outside or in-between layers of the suit.

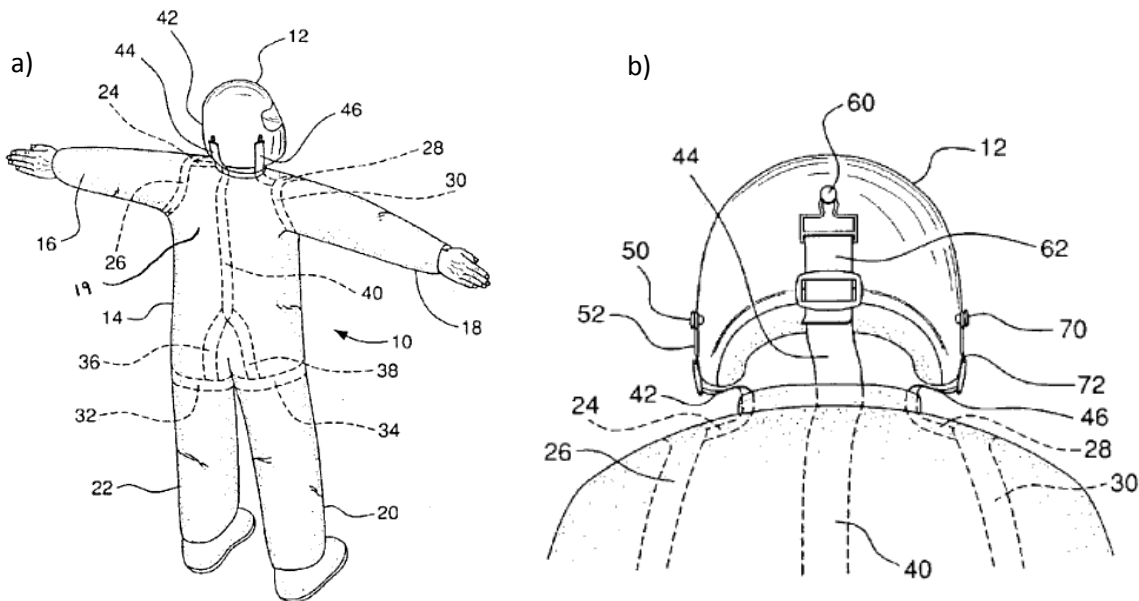


Figure 20. Patent Number 6813782: Figure 20a. Whole System of Tethers. Figure 20a. Close Up of Attachment to the Helmet (Klintzi, 2004)

The “device” features quick releases in order for the helmet to be disconnected from the suit/straps so the helmet can be quickly removed. In addition to the straps that attach to the helmet, there are additional straps that provide support and runs along the back of the user. It then splits into two separate straps, which continue around the legs (Klintzi, 2004).

2.5.6. Patent Number US 20090144886 A1

This invention was patented to Mark A. Stile of HANS Performance Products on June 11, 2009. The key features of this design are the yoke, sleeve and tether, where the yoke acts as a rigid support with respect to the body of the driver. At least one sleeve is attached to the yoke to secure the tether that is passed through at the point where both ends of the tether should be attached to either side of the helmet. Figure 21 shows an annotated schematic, where 15 is the tether, 24 is the sleeve and 34 is the yoke.

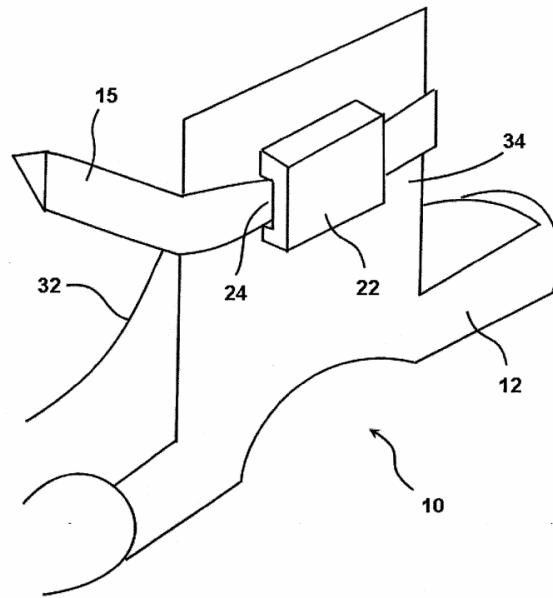


Figure 21. Yoke, Sleeve, and Tether (Stiles, 2009)

This restraint method allows the user to have more freedom as they should be able to turn their head from side to side and still maintain protected from extreme forces and displacement of the head in the forward, side-to-side and vertical directions. This basic design is implemented in all HANS devices in use today (Stiles, June 2009).

2.5.7. Patent Number US 20090229042 A1

This is another invention patented to Mark A. Stiles of HANS Performance Products, but this device is not currently used in any racing divisions. A schematic of this device is depicted in Figure 22. Key design features of this device are the collar and tethers. Both the tethers (40, 42 below) and the collar (20, 22, 24, 27, 30, 36 below) contribute to reducing the displacement and shock experienced when the head of the user is tilted to either side.

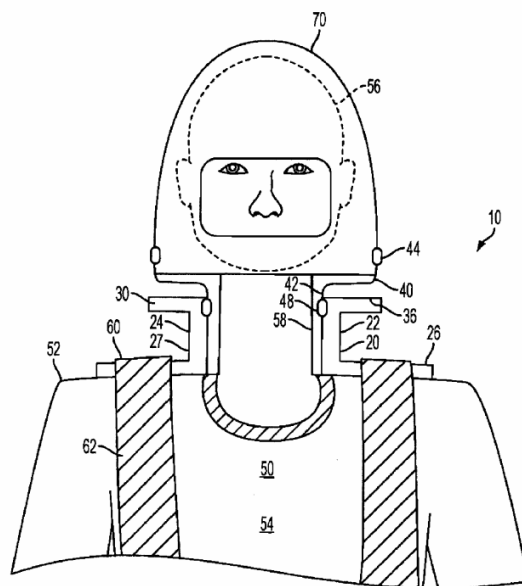


Figure 22. Yoke, Sleeve, and Tether (Stiles, Sept. 2009)

This restraint method is only designed to limit the displacement of the head coplanar to the user's back. Therefore, this should be used in conjunction with another restraint that limits the head in other directions. This device provides extra protection, but limits more of the user's movements. Given that this device does not limit the movement of the head in multiple directions, it is not used in racing today (Stiles, Sept. 2009).

2.6. SFI Foundation Inc.

All products that are available to the public must satisfy certain specifications to ensure that each product is of high quality. As a result, an assembly of racing product manufacturers convened in 1963 to form an association known as the Speed Equipment Manufacturers Association, or SEMA, to formulate the necessary specifications for equipment used in racing. After the association's creation, they encountered extreme difficulty when developing and implementing various product specifications due to confounding variables in the areas of design

criteria, testing, and promulgation of the specifications. Through hard work and dedication, SEMA generated specifications that were eventually accepted by the racing community, which permitted their placement into sanctioning body rulebooks across the United States.

In 1973, SEMA began to focus on the matters of legislation, government regulation, and other activities common to a professional trade association that serves to the interest of a progressive industry. Within the organization, the SEMA Service Bureau was established to take responsibility for the specifications program. Due to the growth in popularity of racing, a more sophisticated and expanded industry specifications program was needed, which instigated the creation of the SEMA Foundation Inc., or SFI, as a replacement for the SEMA Service Bureau.

Since the institution of the SEMA Foundation Inc., the organization became independent from SEMA and shortened its name to SFI Foundation Inc. As its funding comes volunteering companies that participate in the specifications program, SFI has developed different programs for almost eighty products, including head and neck restraints, used by manufacturers, motorsports groups (SFI Website).

2.6.1. SFI Specification 38.1

The SFI Specification 38.1 establishes test procedures and basic standards for the evaluation in the determination of performance capabilities for head and neck restraints. The preliminary portions of the specification involve detailed definitions of a head and neck restraint, the materials used, and the document's purpose. Following the basic definitions is the essential information regarding the requirements for testing. As the potential users will vary in size, the testing dummy for these devices should be the same size as a 50th percentile male and seated and restrained as a real driver would be in a racing event. The test sled used for the crash test should mimic the seating position in typical racing vehicles to ensure that the orientation of the dummy

is similar if not in the exact position that a driver would be in normally. This specification requires that the test sled be able to produce a peak pulse of 68G, which is the equivalent of a 39.1 mile per hour velocity change. Using this acceleration pulse, three crash tests are involved in the certification of head and neck restraints. Two frontal tests and one 30° right front test are performed to determine the functionality of the device in different crash settings. The data collected regarding the forces experienced in a crash for these tests are analyzed for the first 80 milliseconds and again at 120 milliseconds of the test (SFI Specification 38.1, 2011).

Since the purpose of a head and neck restraint is to prevent injuries in those regions of the body, two specific models will be used to assess whether the device effectively limits the movement of the head and neck while the torso is restrained using the data from the crash tests. These models are known as the Head Injury Criteria (HIC) and the Neck Injury Criteria (N_{ij}). The HIC, which is defined by the Federal Motor Vehicle Safety Standard (FMVSS), presents injury as a function of acceleration and pulse duration of the head acceleration at impact. These variables are in reference to the center of gravity of the driver's head. The formula of the Head Injury Criteria is: $HIC = \max\left[\left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt\right)^{2.5}\right](t_2 - t_1)$ where $a(t)$ is the resultant head acceleration expressed as a multiple of the acceleration of gravity ($g = 9.8 \text{ m/s}^2$) and $(t_2 - t_1)$ signifies the time interval. This equation has been used in various studies with a time interval of 36 milliseconds; with that as the interval, the maximum HIC value should not exceed 1000, because anything greater would result in significant head trauma.

For the Neck Injury Criteria, specific loads and moments are used in reference to the upper neck of the driver for the duration of the crash. These loads include axial forces, which can be either in compression or in tension, and shear forces, which are loads perpendicular to the neck column. Data regarding the tension and compression that result in injuries have been

published; the peak tension must not exceed 4170 Newtons (N) and the peak compression must not exceed 4000 N. The N_{ij} strictly entails a calculation using the axial loads and the bending moment about the occipital condyle, which is a protrusion on the skull that forms a joint with the first cervical vertebra. The formula for this criteria is $N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}}$, where F_z is the axial force, F_{zc} is the critical value of load used for normalization, M_y is the bending moment about the occipital condyle, and M_{yc} is the critical value for the moment used for normalization. For the axial load (F_{zc}), the critical value in tension is 6806 N and the critical value in compression is 6160 N. In terms of the moment (M_{yc}), the critical value in flexion is 310 Newton-meters (Nm) and the critical value in extension is 135 Nm. Sources show that a calculated N_{ij} exceeding 1.0 results in a neck injury (U.S. Department of Transportation; Teng, 2004). If these equations yield values higher than the specified requirements, then the head and neck restraint does not comply with the SFI Specification 38.1. Additional tests are required for compliance as well, which can be seen in the complete version of the SFI Specification 38.1 seen in Appendix A.

3. Problem Statement

The prevalence of neck injuries and basilar skull fractures in motorsports caused many sanctioning bodies in top-tier auto-racing divisions, such as National Association of Stock Car Auto Racing (NASCAR), Sports Car Club of America (SCCA), and National Hot Rod Association (NHRA), to mandate the use of a head and neck restraint. The most popular restraint in use, the Head and Neck Safety (HANS) device, has played an instrumental role in the racing world by reducing the overall number of injuries in competition. However, the HANS device has inhibited drivers from exiting the car in emergencies as it can become entangled in the window nets, roll cages, or the ground depending on the orientation of the car. Generally, this entanglement occurs due to the inability to remove the HANS device while wearing a standard racing helmet. As a result, the Motorsports Safety group is working to design and prototype a head and neck restraint device that can be removed easily while wearing a helmet to facilitate exiting a car in an emergency.

4. Design Specifications

Design specifications were formulated to be used as guidelines when evaluating the preliminary designs. The design specifications for this project in no order of importance are:

- **The device must cost less than \$750**

The final product should be sold at a competitive price; however, the price should not be too high so that it is affordable for future users. Additionally, as money is a constraint for this project, the cost of the materials and manufacturing should be minimized as much as possible.

- **The device must weigh less than three pounds**

As the product will be worn on the shoulder area, the total weight of the head and neck restraint should be minimized to ensure that it does not cause added discomfort.

- **The device must be able to be removed quickly in non-crash-like situations**

The device should be able to be taken off the driver by the driver themselves or someone outside of the car after a regulatory race within five seconds or less. This will ensure that the device can be removed in a short period regardless of the environment.

- **The device must be able to attach to SAH2010 style helmets that feature pre-drilled mounting holes**

The final product should be able to attach to standard racing helmets using the same method that the HANS device uses. No additional modifications or products should be required for securement.

- **The device must not interfere with the use of a five- or six-point racing belt harness**

The device should permit a five- or six-point racing belt harness to be fastened securely as it would under normal conditions for safety.

- **The device must maintain original shape and stiffness while in temperatures ranging from 20°F to 135°F**

It is necessary for the structure of the device to maintain its original properties so that it will be able to protect the driver accordingly. If the material properties change drastically in that temperature range, the device will fail to protect the driver as its rigidity will decrease.

- **The device must require recertification no sooner than five years**

SFI Specification 38.1 states that each Head and Neck Restraint must be recertified every five years after the date of original certification. It would not be advisable to make this occurrence more frequent as that might deter users from purchasing this product (SFI Specification 38.1, 2011)

- **The device must be easily cleaned after each use by the user using simple household cleaning products (i.e. Fantastic, Simple Green, etc.)**

The procedure of cleaning the device should not entail any excessive manual labor that requires special training or assistance. Generic household products should be able to be used to ensure a proper level of sanitation.

- **The design must comply to SFI 38.1 Thermal Testing, as noted in Appendix A**

The thermal load shall be applied by a gas Bunsen burner with an inside diameter of 0.4 inches (SFI Specification 38.1, 2011).

- **The device must not obstruct the vision of the driver who is wearing the helmet (i.e. no obtrusions or parts of the device should be in front of driver's helmet)**

Helmets reduce side vision about 41°, which is the equivalent of 16% impairment (Helmet Page). The device should not increase the impairment.

- **The device must comply with SFI 38.1's Impact Performance Specifications (see Appendix A for specifics) (SFI Website)**
- **The straps, tethers, and methods of securement of the device (to the user and helmet) must be adjusted without the aid of specialized tools**

All adjusting associated with the device should be able to be done using tools that are found in a standard toolbox.

5. Preliminary Designs

In order to arrive at a solution to the given problem statement, three preliminary designs were formulated based on a yoke-like structure. Although each design uses involve the same base structure, the designs differ in terms of the method of its removal while wearing a standard racing helmet.

5.1. Quick Release and Split Design

The first preliminary design is the Quick Release and Split design. The base structure of this design is a yoke with two wings that function in stabilizing the device as it is worn over the shoulders similar to a regular HANS device. A tether will be wrapped around the exterior of the top region of the yoke, and it is attached to the SAH style helmets that are equipped with pre-drilled holes for proper securement. While being used in a closed or open cockpit racecar, the five- or six- point harness would rest on top of the two wings of the yoke to serve as an additional anchor of the device. Figure 23 displays the yoke structure connected to the helmet via a tether.

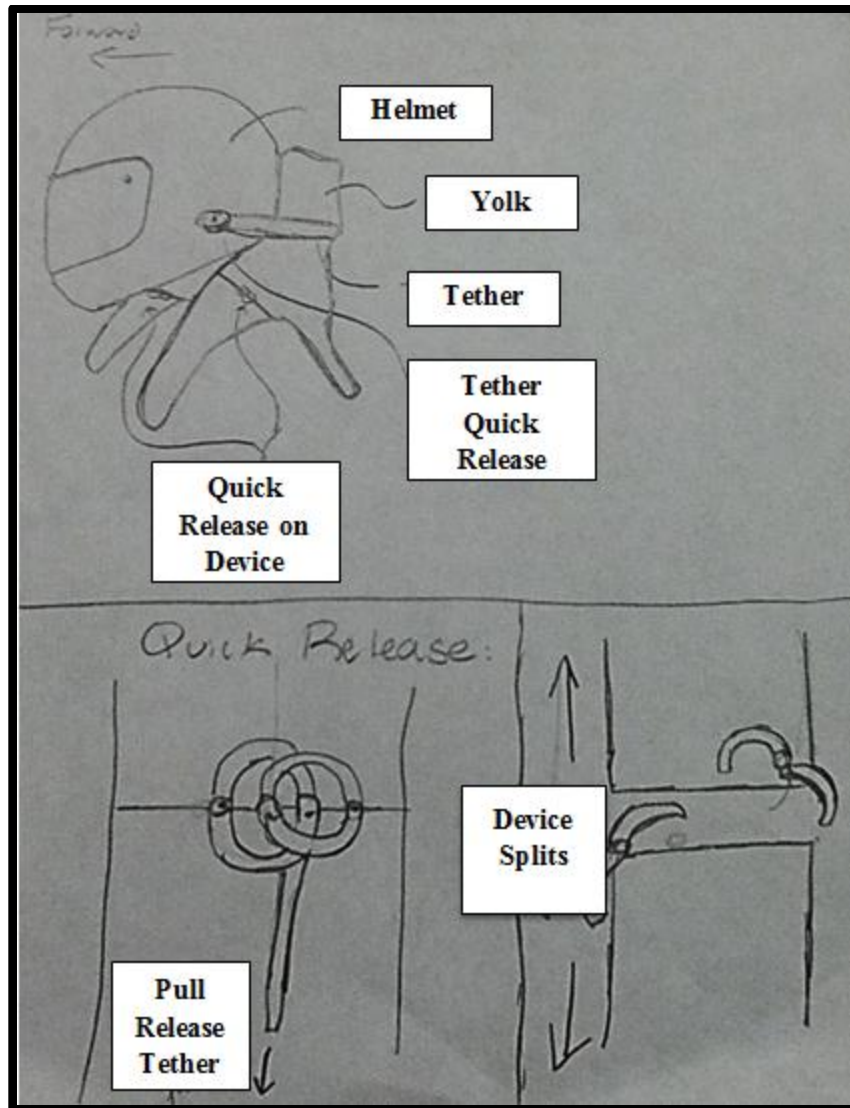


Figure 23. Quick Release and Split Design

To permit quick removal of the device, the yoke is deconstructed into three separate parts: the main neck support and two wings, which are completely detachable. These wings are held into place via quick releases. The bottom of Figure 23 shows a pattern that forms an 8-shape, which is the latch of a double-quick release. Connected to the quick release system is another tether, which opens the latch connection when pulled downward. After the connection in the latch is broken, the wing is able to split off the main body of the yoke. This procedure allows the user or an assistant to take off the device without having to take off the helmet.

5.2. Peg and Hoop Design

The second preliminary design is the Peg and Hoop Design. The main portion of the design is also a yoke with two wings that assist in stabilizing the design as it is worn over the shoulders. To secure this design, a tether will wrap around the posterior portion of the device and attach to the pre-drilled holes in the SAH2010 style helmet. Quick release mechanisms are located at both ends of the tether to allow easy removal. This design also includes detachable wings, meaning the yoke assembly is constructed of three parts as well. However, the wings attach to the main body of the yoke in a way similar to Lego blocks. Both wings have four holes, which are located at the top portion of each wing. The positions at which the wings attach to the body of the yoke exists four pegs. The wings simply link onto the pegs to prevent translation of the device while in use. The five- or six-point harness will rest on top of the wings and the forces it exerts on the body will act as an anchor to secure the device. Figure 24 depicts a sketch of this design, including a magnified sketch of the peg and hoop connection.

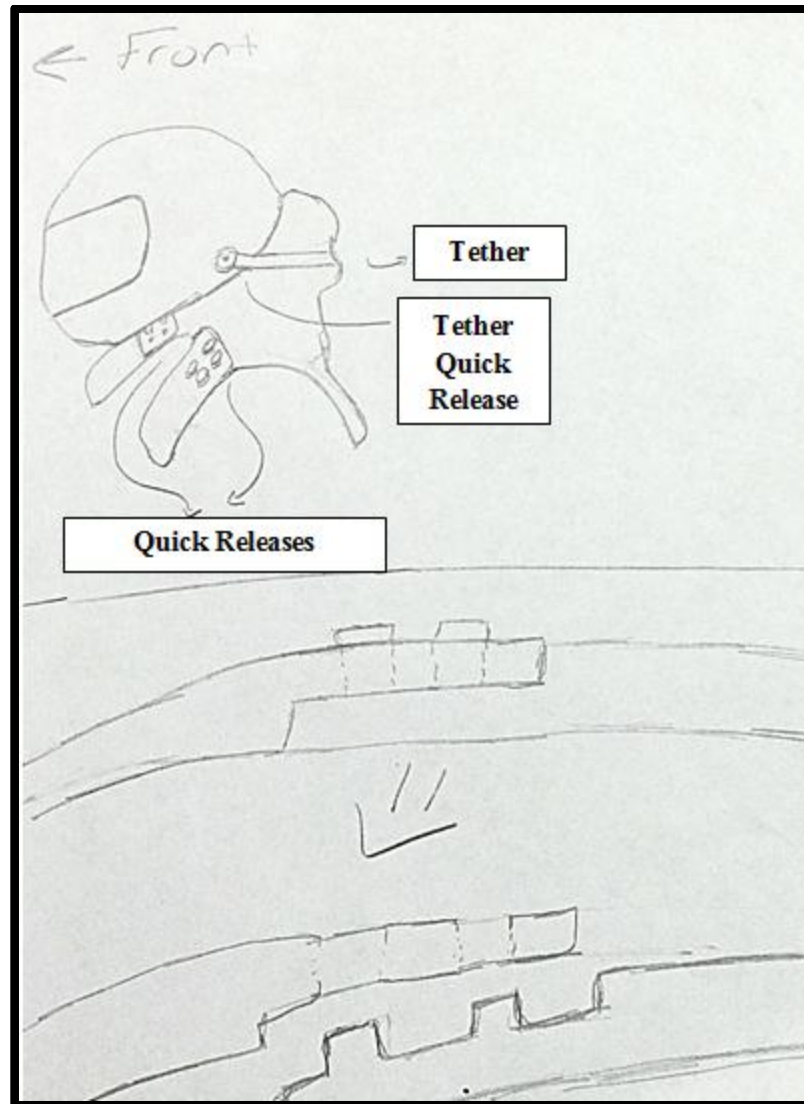


Figure 24. Peg and Hoop Design

This method of quick release will allow the driver to remove the device easily, because once the harness is unlatched, all the driver needs to do is pull up on the two wings and they will release from the hooks. This design enables the driver to remove the head and neck restraint without removing their helmet.

5.3. Hinged Design

The third preliminary design is the Hinged design. This design includes a yoke with two wings that rest on the shoulders to stabilize the device. Like the HANS device, this design attaches to the SAH2010 style helmet in a similar fashion. A tether equipped with a quick release mechanism on both sides is inserted to the pre-drilled holes and fastened appropriately. Unlike the other preliminary designs, this design does not involve detachable wings; however, this design includes hinges so the wings can pivot to allow the removal of the device.

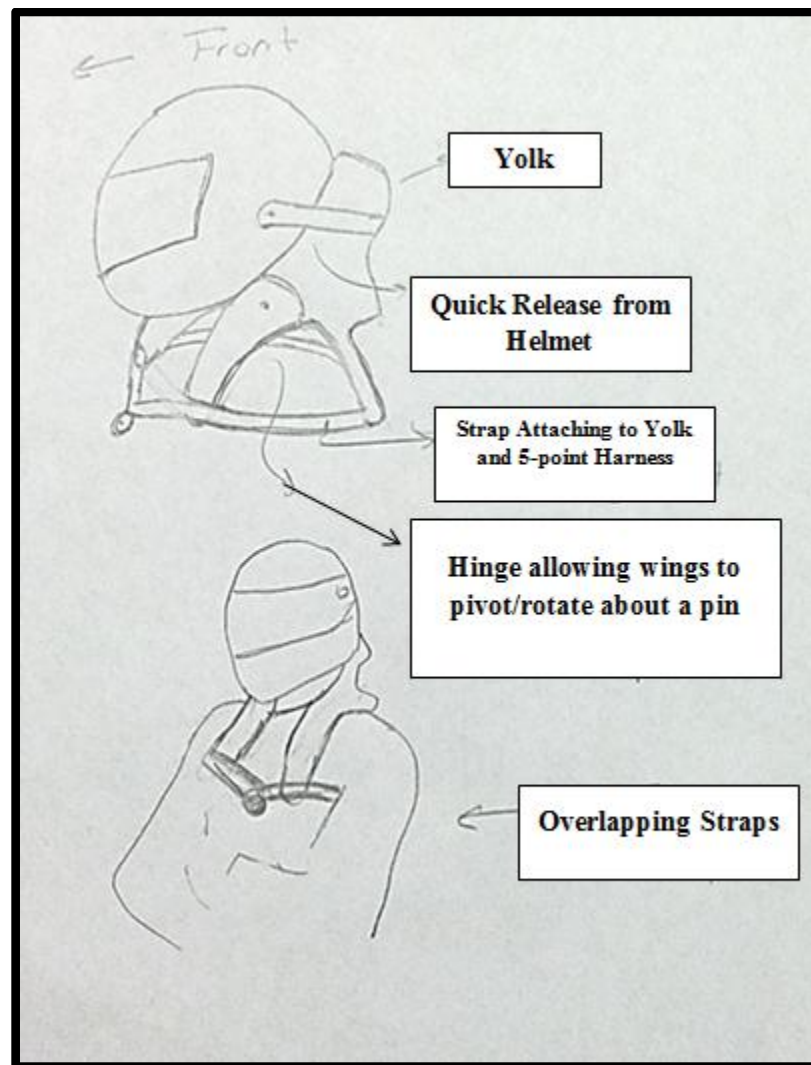


Figure 25. Hinged Design

To keep the wings in place, the five-point harness will be placed on top and act as the anchor. Another unique feature of this design is an additional strap that wraps around the back of the driver and overlaps the two wings. Acting as a second anchor, this strap meets at a point that can hook onto the five-point harness. Once the harness is unlatched, the strap can be lifted up to allow the wings to be pivoted accordingly. This device can be removed easily while wearing a standard helmet.

6. Design Selection

The process of selecting a final design incorporates several different steps, including ranking the specifications, generating a weighting system, and using a decision selection matrix to evaluate the preliminary designs. All of these steps are described within the following sections.

6.1. Pairwise Comparison Chart

Before assessing the preliminary designs, the design specifications had to be ranked in order to determine each specification's relative importance when compared to the other specifications. These ranks were determined through the completion of a pairwise comparison chart. Organizing the specifications in both the first column and the first row, the specification in the first column is compared to the others specifications located in the first row; if it is superior to the specification in the row, it is given a value of one. If the specification is assessed to be less important than the one located in the row, a value of zero is given. If both are of equal importance, then a value of one-half is given. Table 2 shows the completed pairwise comparison chart with all of the design specifications that were used as ranking criteria.

Table 2. Pairwise Comparison Chart

	# of Comp.	Ease of Use	Manu.	Comfort	Cost	Weight	Dura.	Maint.	Adjust	Safety	Totals
# of Components		0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0
Ease routine of use	1.0		1.0	0.5	1.0	1.0	0.0	1.0	0.5	0.5	6.5
Ease of Manufacturing	0.5	0.0		0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.5
Comfort	1.0	0.5	1.0		1.0	1.0	0.5	1.0	1.0	0.0	7.0
Cost	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0
Weight	0.0	0.0	1.0	0.0	1.0		0.0	1.0	0.5	0.0	3.5
Durability	1.0	1.0	1.0	0.5	1.0	1.0		1.0	1.0	0.0	7.5
Ease of Maintenance	0.0	0.0	1.0	0.0	1.0	0.0	0.0		0.0	0.0	2.0
Adjustability	1.0	0.0	1.0	0.0	1.0	0.5	0.0	0.5		0.0	4.0
Safety/Emergency Use	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0		8.5

Based upon Table 2, the totals located in the right column were extracted to assess the relative rankings of all the specifications. Table 3 contains the information regarding relative rankings and the totals from the pairwise comparison chart.

Table 3. Relative Rankings of the Design Specifications

Specification	Total	Ranking
Safety/Emergency Use	8.5	1
Durability	7.5	2
Comfort	7	3
Ease of Routine Use	6.5	4
Adjustability	4	5
Weight	3.5	6
# of Components	2	7
Ease of Maintenance	2	7
Ease of Manufacturing	1.5	9
Cost	0	10

From the evaluation of the design specifications, it was determined that the most important was the safety of the device, specifically in emergencies. As the purpose of the device is to protect the driver from acquiring severe injuries, the focal point of each preliminary design

should always resort to whether the basic concepts of the design maximize the safety for the driver in all situations by assuring that it can reduce the movement of the head and neck. The other portion of this specification is the ease of use in an emergency. As a goal of the project is to remove the device before exiting an enclosed cockpit car, decreasing the time for its complete removal would make exiting the car more advantageous in crash-like situations. Ensuring the ease of use in an emergency is vital to the success of the device, as it allows the driver to escape dangerous situations quickly. Durability received the second highest score among the specifications. If device fractured while in use under typical racing conditions, it could injure the driver depending on the location of the breakage and cause irritation, potentially affecting the driver's performance. Additionally, in crash-like situations, the device would not be able to reduce the movement of the driver's head and neck with its intended ability meaning that drivers could still acquire serious injuries. Following durability, comfort was the next highest ranked specification. Despite the fact that comfort does not seem as important of an objective, many drivers expressed their feedback about the discomfort that their head and neck restraint caused them. Due to these claims, it seemed appropriate to place comfort as one of the top priorities within the design process. The ease of routine use also ranked relatively high among the specifications, because increasing the overall complexity of the device would discourage drivers from using it as the process of securing it might be tedious. The other specification that was viewed to be important was adjustability. As all racecar drivers are not of a uniform size, it is necessary to incorporate adjustable anchors in the system, so the device can be secured tightly to differently-sized drivers in order to enhance its overall performance. Therefore, the evaluation showed that the critical specifications that deserve the most recognition throughout the design process are safety, durability, comfort, ease of routine use, and adjustability. That being said, the

other specifications (in Table 3) can be viewed as desirable objectives rather than absolutely necessary to guarantee the device is successful.

6.2. Weighted Rankings

After the specifications were compared using the pairwise comparison chart, they each were assigned a weight. These weights were assigned to each objective as a means of distinguishing their overall importance to the design. The weights were selected in a way so that the sum of all the weights is 100. Table 4 includes all of the design specifications and their associated weights.

Table 4. Design Specifications with Pairwise Comparison Results and Weighted Rankings

Specification	Total	Ranking	Weighting
Safety/Emergency Use	8.5	1	25
Durability	7.5	2	18
Comfort	7	3	14
Ease of Routine Use	6.5	4	12
Adjustability	4	5	10
Weight	3.5	6	7
# of Components	2	7	5
Ease of Maintenance	2	7	5
Ease of Manufacturing	1.5	9	3
Cost	0	10	1

Safety, the most important design specification, was given a value of 25. As durability and comfort ranked high, they received a weight of 18 and 14 respectively. Although they were .5 apart in total based on the pairwise comparison chart, the durability of the device should be viewed as more important. This is because it could affect whether the driver will sustain any injuries, while comfort is ideal but can be overlooked if necessary. Slightly less important, ease of routine use and adjustability were given weighted scores of 12 and 10 as they both ranked in

the top five specifications. With the sum of the weights of the five most important being 79, the remaining specifications were assigned weights to ensure that the total came to 100. Although cost received a zero from the pairwise comparison chart, it still received a weighted ranking as an elevated cost could discourage future users from purchasing the device.

6.3. Decision Selection Matrix

A decision selection matrix was used to evaluate the three preliminary designs. To utilize this method appropriately, a matrix was generated with a list of the design specifications in the first column and the preliminary designs listed in the first row. A five point scale was used to rate each design in terms of how well it satisfied the given specification. The highest score a design can receive (without applying the weighting) is a five, signifying that the design meets the specification in an exceptional manner. The assignment of a one would mean that the design would not meet the specification. Table 5 contains information regarding the five points that can be assigned within the matrix.

Table 5. Five Point Scale for the Completion of a Decision Selection Matrix

Number	Assessment
1	Unsatisfactory
2	Below Average
3	Average
4	Above Average
5	Exceptional

With an established rating system, the decision selection matrix was filled out based on the original assessment of the preliminary designs. Each member of the group filled out the decision selection matrix individually first; when each member assessed each design in terms of all of the specifications, a meeting took place to deliberate to come to a consensus regarding the

assessment of each design. This method of evaluation was performed as a means of ensuring that no single member dominated the discussion to sway the final tabulated results. Table 6 shows the completed decision selection matrix.

Table 6. Decision Selection Matrix

	Weighting factor (out of 100)	<i>Design Alternatives</i>					
		Quick Release and Split		Peg and Hoop		Hinged Design	
		<i>Rating</i>	<i>Weighted</i>	<i>Rating</i>	<i>Weighted</i>	<i>Rating</i>	<i>Weighted</i>
<i>Specifications</i>							
Safety/Emergency Use	25	5	125	2	50	2	50
Durability	18	4	72	3	54	3	54
Comfort	14	4	56	2	28	3	42
Ease of Routine Use	12	4	48	5	60	2	24
Adjustability	10	1	10	1	10	4	40
Weight	7	3	21	4	28	3	21
# of Components	5	3	15	5	25	4	20
Ease of Maintenance	5	4	20	5	25	4	20
Ease of Manufacturing	3	4	12	4	12	2	6
Cost	1	3	3	4	4	3	3
	Totals	35	382	35	296	30	280

By examining the totals of the un-weighted ratings of each design after the completion of the decision selection matrix, a definitive decision cannot be made as two of the designs had the same score. Ultimately, this instance provides the rationale of weighting the specifications to demonstrate which specifications should be regarded with higher importance. Applying the weighting factors to the ratings provides differentiation in the results amongst the three designs. Of the three designs, the Quick Release and Split design received the highest score of 382, which was most likely contributed to its enhanced safety aspect and ease of use during an emergency. The Peg and Hoop design and the Hinged design both acquired ranks that were relatively close to each other; however, the Peg and Hoop design received a slightly higher weighted score of 296,

which can be attributed the high scores for ease of routine use and overall weight. Although it obtains the lowest overall score, the Hinged Design permits the highest degree of adjustability due to the wing's ability to pivot about a pin, but its low rating for safety and emergency use acts as a major deterrence from it being selected as the final design.

6.4. Selection of Final Design

From the results of the matrix and further analysis, the Quick Release and Split design proved to be the best design concept amongst the three. Although it is not superior in every design specification, this design incorporates detachable wings that are secured to the body of the device via quick release mechanisms. In the case of an emergency, the mechanisms that attach the wings to the body of the device can be switched to the released position to permit its complete removal in a matter of seconds. The inclusion of the quick release mechanism guarantees that the driver will be able to remove the device prior to the exiting of the car, which facilitate the task of doing so considering they will not have to contort their backs as they would with a regular head and neck restraint. Compared to the other designs, the Quick Release and Split design probably would involve the most parts making it the most expensive. Another potential drawback of this design is that the wings of the device cannot be positioned at different angles for users of various sizes. However, the advantages outweigh the disadvantages, because the design's capabilities will enable the user to escape dangerous situations more easily, which will decrease the chance of acquiring severe injuries and will permit those who do become injured to receive care sooner.

7. Detailed Design

The results of the decision selection matrix assisted the group's decision to select the preliminary design concept on which the Quick Release and Split design was based. Using that design as a foundation, a more detailed design for the device was generated in order for the device to function properly. In the case of high-speed crashes, the environment that the user is subjected to involves elevated forces induced by the deceleration of the vehicle; to compensate for these excessive loads, the device is to be comprised of multiple substructures as a means of withstanding and distributing the resulting forces. Through deliberation and ideation, the main substructures in the device were determined to be the skeleton, the core, and the joint. The following sections describe these three substructures in detail.

7.1. Skeleton

Analyzing the design from a manufacturing standpoint, the device could be constructed of solely carbon fiber if a few alterations are made. The usage of large quantities of carbon fiber would increase the associated costs for the manufacturing of the device. This would also require the design for the device to increase in overall complexity in order to ensure its reliability while in use. Consequently, a "skeleton" is to be placed within the device in order to act as its supporting structure. Given the component's principal function, the skeleton must be fabricated using a material with a relatively high yield strength to reduce the possibility of the fracturing of the device. As a result, .25" diameter, aluminum rod was originally selected as the material for this structure as it is easy to machine, weld, and bend while still maintaining its suitable properties for withstanding high forces.

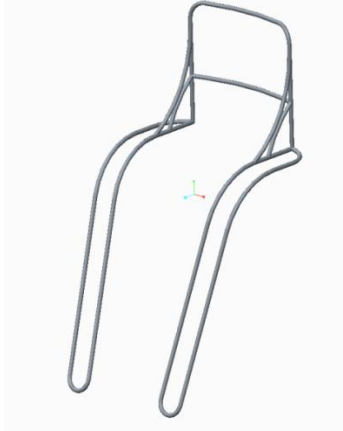


Figure 26. Model of the Skeleton Substructure with .25" Diameter Aluminum Rods

The model for general structure of the continuous skeleton is displayed in Figure 26. To increase the rigidity of the back portion of the device, additional vertical pieces of aluminum were added to the structure. The orientation of these additional members is displayed in Figure 27.

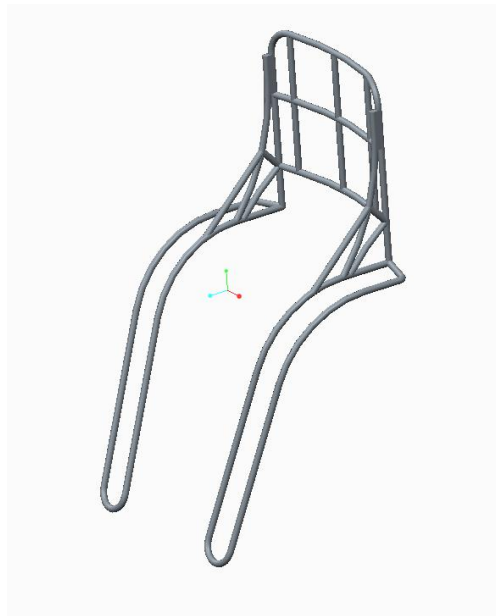


Figure 27. Model of Skeleton with Reinforced Back Portion with .25" Aluminum Rods

Although the additional vertical bars were added to provide more support, initial analysis demonstrated that the .25" diameter is not strong enough to withstand the forces to which the device is exposed. Consequently, decisions had to be made in regards to the dimensions of the

material to be used for this substructure. Based on its higher resistance to bending forces, .625" aluminum tubing with an inner diameter of .375" was selected for the material for the skeleton instead of .25" aluminum rods. Not only will the implementation of aluminum tubing increase the relative bend strength of the device, but also it will reduce the total price and weight of the device in comparison to that of solid aluminum rods. Due to the changes in diameter, the design of the skeleton had to be altered as the radii related to the bottom portion of the device with the .25" iterations cannot be manufactured using .625" tubing.

To compensate for the increase in diameter of the aluminum, the updated version of the back portion of the skeleton was designed to withstand the bending moment exerted during a crash while consuming the least amount of space as possible to minimize the size of the joint block. Figure 28 displays the back part of the prototype design.

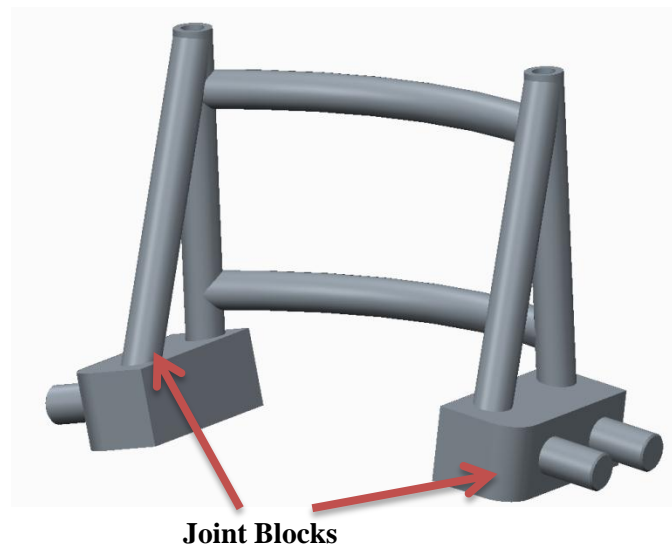


Figure 28. Model of the Back Region of the Prototype Design

This portion of the device rests on the shoulders and extends six inches, which is about the average height of the center of mass of the head relative to the top of the shoulders. The two tubes joining the two sides of the device have some curvature to them to allow more space for the head of the driver and for aesthetic purposes.

The other part of the skeletons that had to be redesigned is the actual wings, one of which is displayed in Figure 29.

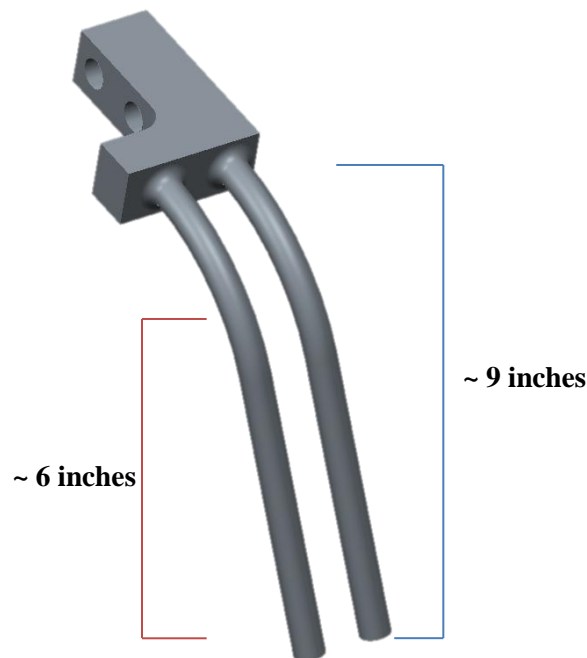


Figure 29. Wing Portion of Skeletal Structure

The total length of a wing from the joint block to the end is roughly nine inches. The angle between the wings and the vertical back piece is at 25° to accommodate for the standard 20° slant of the seat and slight rise of the chest. The radius of curvature at the top part of the wings is four inches, which is small enough to give the desirable change in angle to the wings. The remainder of the wing extends about six inches. These dimensions are similar to the dimensions of the wings on existing head and neck restraints. Figure 30 shows the complete assembly of the skeleton substructure.

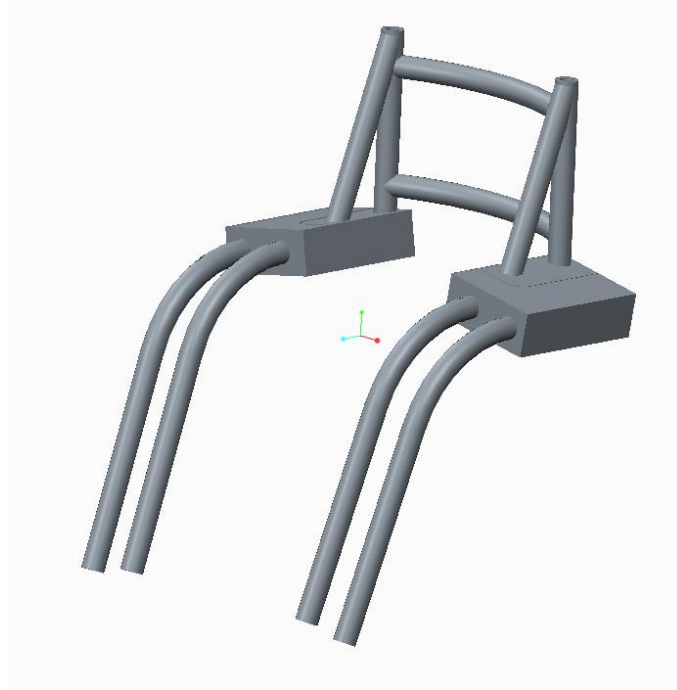


Figure 30. Complete Assembly of Skeleton Structure of the Prototype Design

The safety tethers, which are used to mount to the helmet as a means of restraining the head from snapping forward during crash-like conditions, serve as a vital part in the safety aspect of the device. In order to fasten tethers to the back region of the device, the upper back portion of the device would need to be drilled and tapped so the tethers can be securely bolted to the skeleton of the device.

7.2. Core

The core is simply the body of the device that surrounds the skeleton, which is depicted in Figure 31.



Figure 31. Concept of the Core of the Device

It was decided that this component of the device would be made of foam so the forces exerted on the device during impact can be absorbed. After the foam is properly shaped as specified by the drawings of the design located in Appendix D, the core is then wrapped in fiberglass. Without the application of the fiberglass, the foam alone would not be able to provide the appropriate amount of strength and would fracture easily. Therefore, fiberglass was chosen to surround the foam to support the core to ensure functionality in all driving conditions.

7.3. Joint

Given that the Quick Release and Split design includes removable wings, it is necessary for the structure to involve two locations to join the wings to the body of the device; these locations are known as joints. As the shapes of joints can vary drastically, preliminary research was performed to collect information regarding joint formations currently used in the market. By doing so, a few feasible joint formations were found, including the triple dovetail joint and a jigsaw puzzle type joint. A triple dovetail joint includes a top portion with one large dovetail tenon, or notch, with two smaller ones on the underside of that section. The bottom portion contains openings for the notches to connect to become a closed joint (Wood Joint Instructions). Figure 32 displays the two separate pieces of a triple dovetail joint to visualize the connection profile.

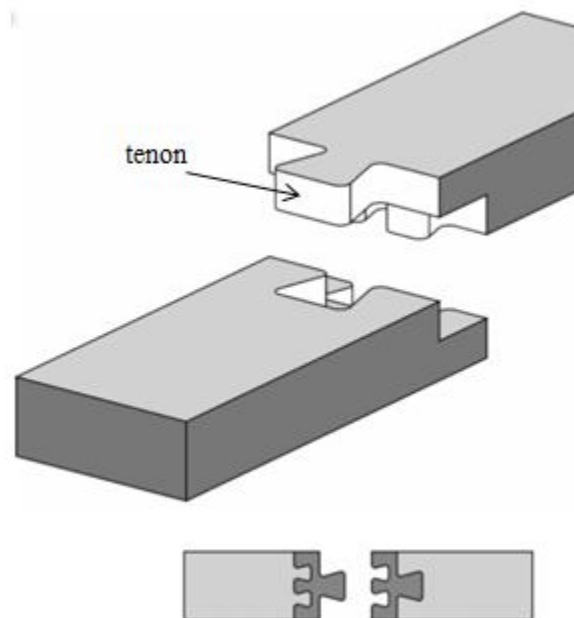


Figure 32. Triple Dovetail Joint (Wood Joint Instructions)

Another popular joint used is the jigsaw puzzle type joint, which incorporates a smooth radius across the tenon, so it is more of a circular region. This design involves two identical parts, and one is flipped over so that a closed connection can be made properly (Roll). Figure 33 depicts the configuration of this type of joint.

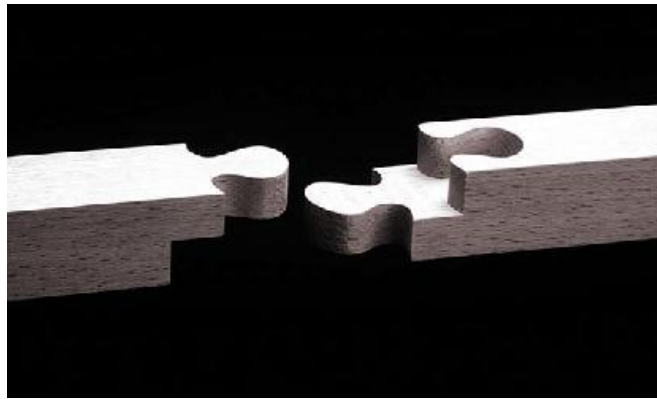


Figure 33. Jigsaw Puzzle Type Joint (Roll)

Considering these joint formations, the joint to be used in conjunction with the skeleton of the device would have to enable the wings to be disconnected easily in a fashion that allows the device to remain structurally sound. With that in mind, a “dog bone”-shaped joint was selected as it would permit lateral translation and restrict translation in the upward and downward directions as needed. Figure 34 shows the “dog bone” shape included in the joint.

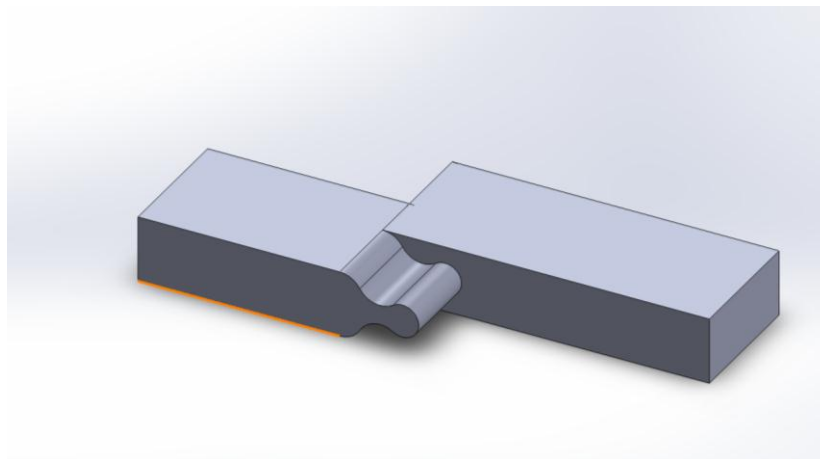


Figure 34. "Dog Bone" Shaped Joint

The other concept that was taken into account during the design of the joint was its overall size. In order to distribute the load properly and attach to the skeleton, the width of the joint should be at least two inches. The thickness of the joint was determined from a manufacturing standpoint as the common stock size involves a width of two inches and a thickness of three-quarters of an inch. With the overall width of two inches, a consensus was made that sliding the free end of the joint two inches laterally would be cumbersome and time consuming, which could be the difference between life and death in a hazardous situation. To decrease the distance needed to slide the joint to allow complete separation, the tenon portion of the joint was offset slightly and flipped in the opposite direction. By doing this, the total distance required to separate the joint is now half the original distance of lateral movement. Figure 35 shows the updated version of one side of the “dog bone” joint to observe the redesign of the internal connection.

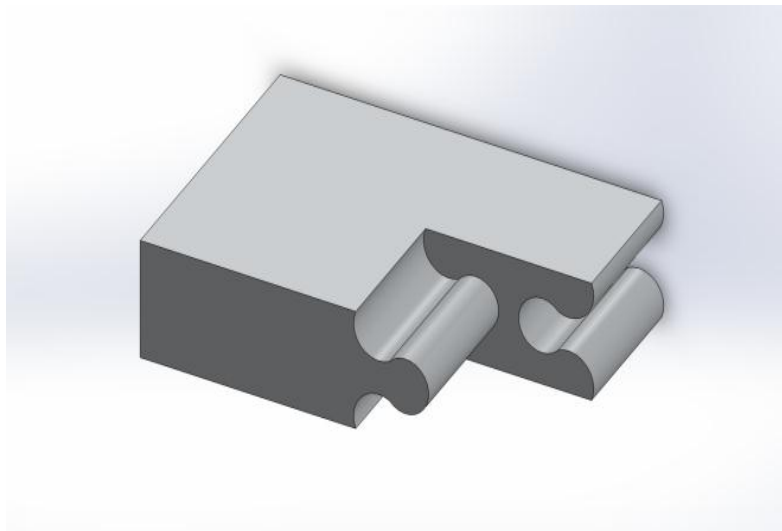


Figure 35. Offset and Flipped "Dog Bone" Joint

In addition to decreasing the distance needed to disconnect the joint, this design is optimal for manufacturability as the complete joint is the part in Figure 35 reproduced. The complete joint with the reproduced side is depicted in Figure 36.

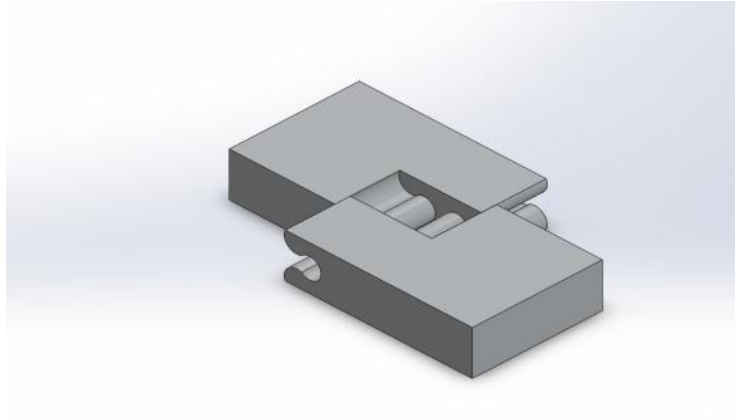


Figure 36. Complete Redesigned "Dog Bone" Joint

Although this design for the joint had beneficial contributions to the structure, preliminary stress analysis of the skeleton equipped with this type of joint, which is depicted in Figure 37, yielded that the device as a whole would have to be much more structurally sound to endure the forces applied in crash-like conditions. However, the implementation of this joint would not be feasible given that the kinematic movement needed separate the two pieces would be difficult with the spatial constraints in a closed cockpit car. As a result, this particular design for the joint was disregarded.



Figure 37. Skeleton with Two "Dog Bone" Joints

Having concluded that the “dog bone” shape joint would ultimately fail in a crash-like setting, a new design was generated that would increase the strength of the back portion of the

skeleton. This would be accomplished by shifting the location of the joint upwards so it would rest on the shoulders; incorporating the solid block near the back portion of the device would act to reinforce that part of the skeleton, which would increase its overall strength. This new joint was designed based on the same concept that the joint should have only one degree of freedom in order for the mates to come apart, but remain resistant to movement in any other direction. The prototype design for the joint displayed in Figure 38 consists of two rods attached to the back portion of the device with matching mates for both on the wings. This design serves the original purpose of allowing the wings to be fully removed from the remaining portion of the device by sliding the wings laterally away from the back region. A set of pressed steel pins was fixed into the back region of the design to form the male half of the joint.

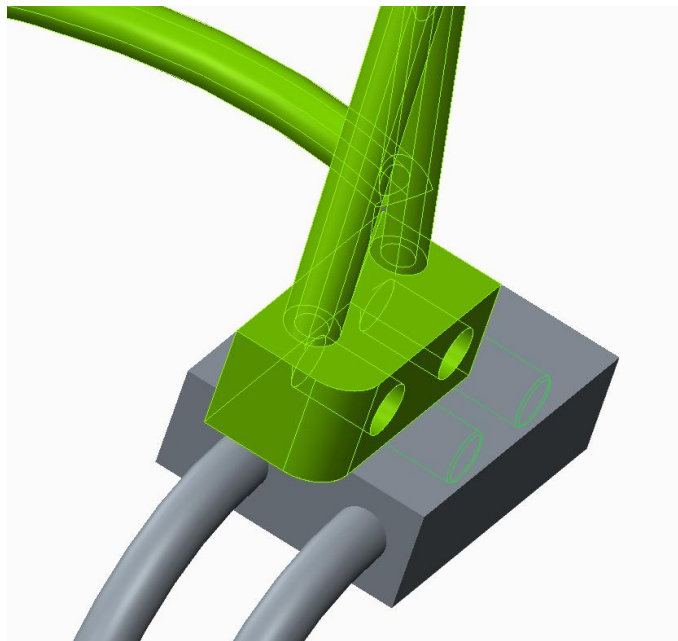


Figure 38. Pin Joint

As the wings function to anchor the device to the user, it is imperative that they be fixed into position while in use. To do this, a latch, similar to the one depicted in Figure 39, will be used to secure the wings to the body of the device.



Figure 39. Brass-Plated Cam Action Window Sash Latch (Home Depot)

In terms of dimensions of the joint block, the thickness at any given section is 1.25". The reason for this is that there needs to be enough material so that an appropriately sized hole can be made to fit the tubes to allow the wings to attach to the body of the device while maintaining a high level of strength. Additionally, holes intended for the back support tubes need to be deep enough to ensure that the connection is secure, and the thickness of the block limits the total depth of the hole. The length of the joint is dependent upon a few factors. The first factor involved is that the device needs to be long enough so that the two tubes that are set on an angle and the back portion of the device make a strong triangle formation. Also, there needs to be enough extra length to have a proper depth for the holes that are made for the wings. Therefore, the total amount of material for the joint must be enough so that the joint itself is able to endure forces experienced in a high-speed crash. The width of the joint is three inches, which provides enough space to include the back portion of the device and for the two-inch belts to rest on top of it. The location where the joint divides is placed where there is enough space to mount a latch across the break point in addition to have enough material to keep the female and male mates strong so that the material does not fracture. The point where the block separates into two pieces is set half the width of the block to satisfy the requirements previously mentioned. Figure 40 depicts the pin joint labeled with the dimensions.

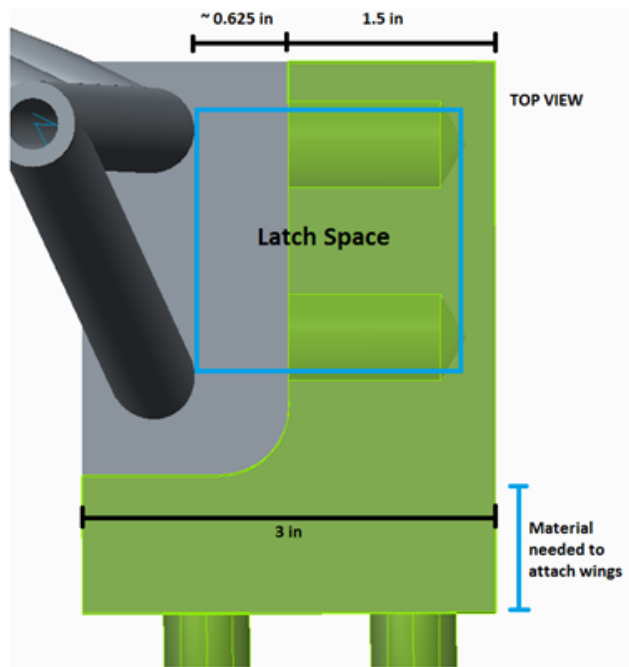


Figure 40. Dimensions of the Pin Joint Assembly

The holes for the joint are .625” in diameter and were placed as far apart from each other as possible to create the maximum amount of leverage possible. The holes were first positioned on the male block, and then the female mates were positioned to match accordingly. The engineering drawings for the parts and the assembly can be seen in Appendix D and Appendix E.

8. Analysis of Final Design

Having developed a CAD model for the final design of the device, in-depth stress analysis of the various regions of the device was necessary to determine if it will function as planned, or if more changes are needed to ensure that the device will remain intact when different loads are applied. Before the analysis can be performed using the software package in Creo, a free body diagram needs to be generated to predict the loading involved with vehicle crashes, and preliminary calculations needed to be carried out to determine the typical forces that are exerted on the body in a crash-like scenario.

8.1. Free Body Diagram

The relative forces that act on the body during high-speed crash conditions were determined with the use of a free body diagram, which is displayed in Figure 41.

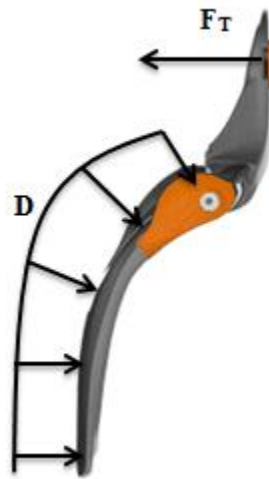


Figure 41. Free Body Diagram of Device during Crash Conditions where F_T is the force exerted by the driver's head and helmet and D is the force from the harness (HANS Device Revolutionizing)

The free body diagram shows only a distributed force, D , along the wings, which is exerted by the five-point harness and a force exerted on the back portion of the device by the tethers, F_T .

Typically, the weight of the device and normal forces exerted on the device from the user would be taken into account, but comparing the magnitudes of the distributed load and the F_T with these values, they can be categorized as negligible. Using this free body diagram and data regarding the typical deceleration involved in crashes in racing competitions, the forces can be determined in order to perform the necessary analysis.

8.2. Preliminary Calculations

Researching data for the highest deceleration experienced in a high-speed crash showed an instance where a driver survived a crash where the deceleration was about 214 G. Comparing that value to decelerations associated with crashes where the vehicle was travelling at 35 mph, the deceleration of 214 G seemed excessively high, which meant more data needed to be researched to find appropriate values for deceleration. As a result, the SFI Specification 38.1 was reviewed again to determine if any values were stated regarding any acceleration. In one of the clauses, it states that a head and neck restraint should be able to withstand an acceleration of 68 G in a physical test. Considering that one of the goals of this project is to satisfy the SFI Specification 38.1, the usage of 68 G as the acceleration in the calculation for the forces on the head and torso is justifiable due to that specific clause. Utilizing the anthropometric data for a 50th percentile male, the forces exerted on the head and torso were calculated to be about 5300 N (~1200 lb) and 19000 N (~4300 lb) respectively (SFI Specification 38.1, 2011). Appendix B shows the procedure that was followed to determine these values.

8.3. Analysis of the Skeleton

The SFI regulations specify that a head and neck restraint device should withstand the acceleration of 68 G in a physical test. Research shows that the HANS device fails at 110G, which yields the device an approximate safety factor of 1.6. For this reason, all analysis of the proposed device assumes a safety factor of 1.6. The calculation for Factor of Safety is completed by determining the ratio between the actual strength and the design strength:

$$Factor\ of\ Safety = \frac{Actual\ Strength}{Design\ Strength}$$

$$Factor\ of\ Safety = \frac{110G}{68G}$$

$$Factor\ of\ Safety = 1.618 \approx \mathbf{1.6}.$$

The forces for the analysis were computed using the safety factor. For this case, the force applied to the top region of the device, F_T , was found to be 8500 N.

The maximum force, which is applied by the belt that holds the device against the body, can be determined by the force applied by the torso. Using a simple model to represent the belt and torso, the maximum force can be estimated. Figure 42 shows the model used to solve for the force.

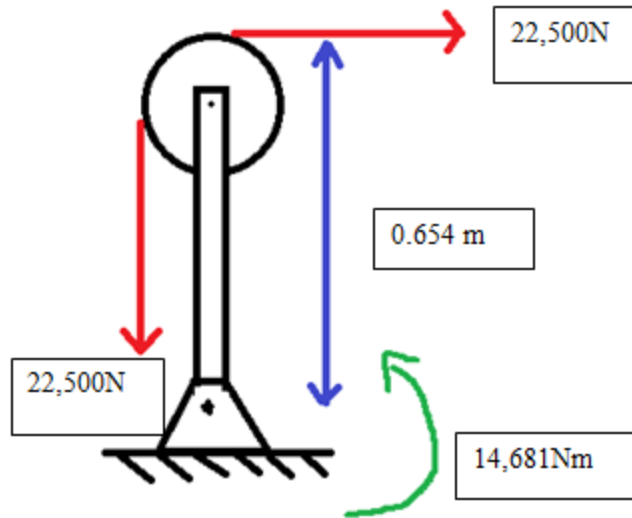


Figure 42. Model to Represent the Torso

$$F = \frac{M_o}{L}$$

$$\frac{14681Nm}{0.654m} = 22,500N$$

The force of the belt was determined to be about 22500 N. Appendix C shows the method followed to determine these values. Since the external forces applied by the harness and the head to the device were determined, the approximate forces acting on the joints can be calculated utilizing the equilibrium equations and the free body diagrams. The basic model depicted in Figure 43 shows half of the back region of the device under full frontal loading, while the front end of the female block is fixed. The vertical green line highlights the location where the wings meet the joint portion, which causes that location to be fixed when in use with a harness. Considering only one joint of the two existing joints is modeled for this analysis, only half of the full frontal force F_T is applied, which is 4250 N.

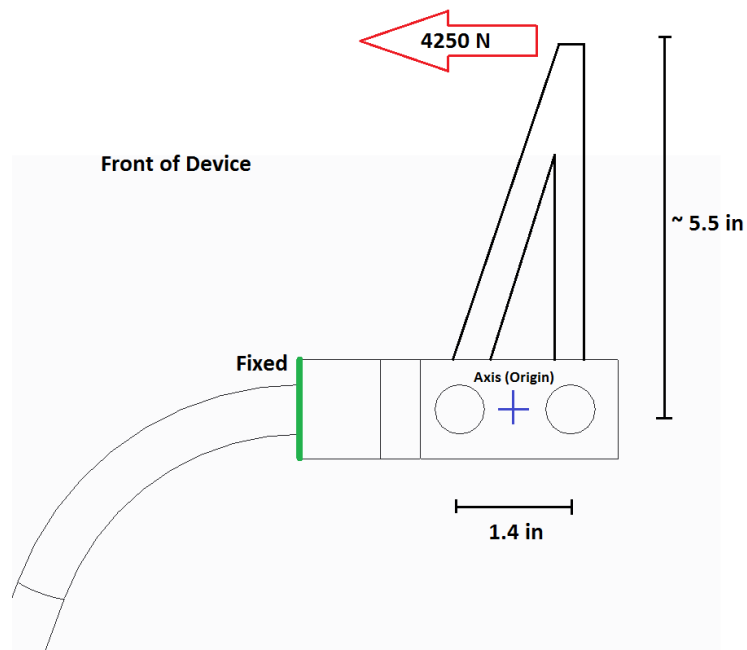


Figure 43. Model Under Full Frontal Loading to Simulate a Frontal Crash

Upon the application of the frontal load, the force is transferred to the female block via the two steel pins, which justifies the decomposition of the load into two separate loads acting directly on the female block.

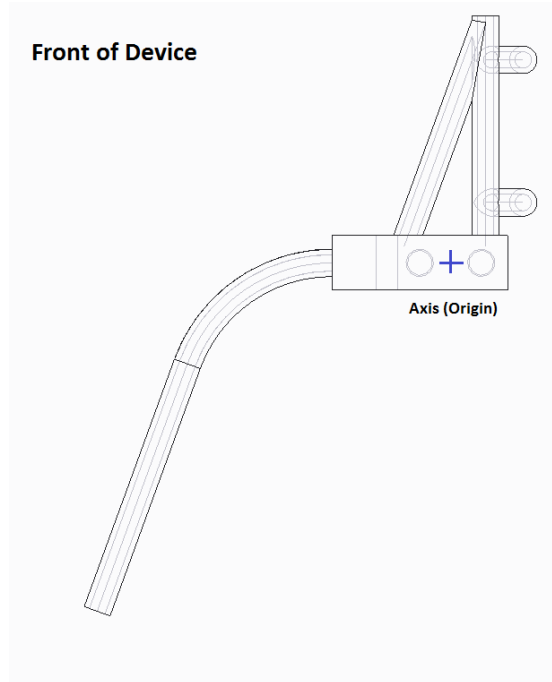


Figure 44. Model of Whole Device with Location of Origin

By treating the back piece as a lever arm, the forces can be determined through a summation of the moments acting at the center axis located between the two pins; Figure 44 displays location of the origin on the device used to determine the forces exerted on the pins. The equation below shows the calculation of the forces applied to the pins.

$$\sum M_1 = \sum Fr$$

$$4250 \text{ N} * 5.5 \text{ in} = F * .7 \text{ in}$$

$$F = 33400 \text{ N}$$

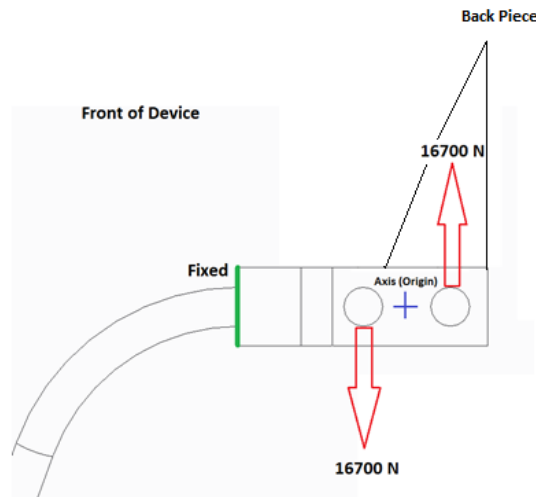


Figure 45. Application of Load on the Block

The total force of 33400 N can be divided equally to represent the loads from the pins as shown in Figure 45. For the analysis, the front portion of the joints was fully constrained, because the wings are attached at that location. The device was then subjected to forces involved in the most extreme crash to determine the maximum stress experienced. Therefore, the stresses generated from the performed analyses were greater than those that would be experienced in crashes involving lower accelerations.

In each analysis, Creo Simulate was used. The force-constraint diagrams show various arrows to signify different forces. For these analyses, the orange arrows represent forces, while the blue arrows represent constraints. The chosen material was 6061 aluminum with an ultimate tensile strength, compressive strength, and yield strength for the aluminum of 45 ksi, 76 ksi, and 40 ksi respectively. Therefore, the stresses must not exceed 45 ksi for any component made from the 6061 aluminum, as fracture would occur. It is desirable that the stresses do not exceed

the yield strength since permanent deformation might reside and lead to failure or malfunction of the joint.

8.3.1. Analysis of the Back Portion and Male Blocks

To simulate forces on the upright back portions of the device, the assumption is made that the wings are fixed (static) and constrained by the belt up to the joint. Figure 46 shows the location of the constraints on the back region of the device.

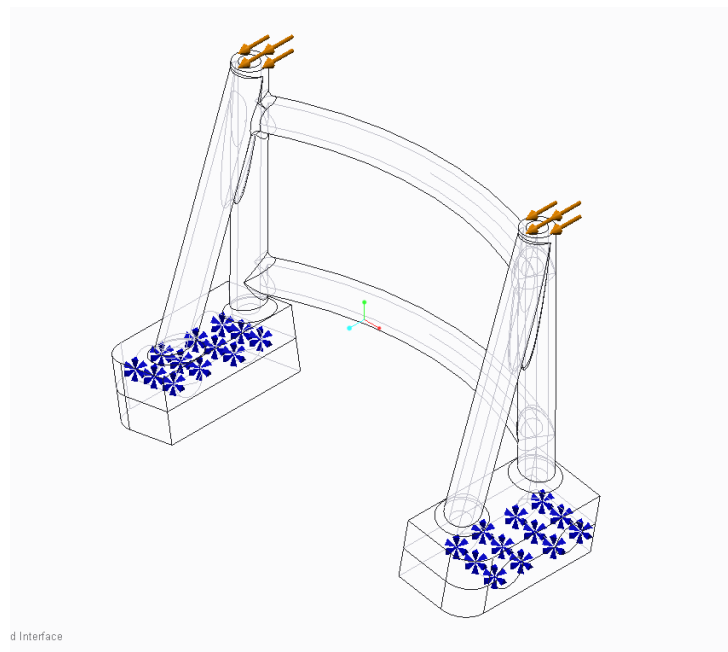


Figure 46. Back Portion of the Device with Constraints Used for the Analysis with the Constraints in Blue and the Loads in Orange

The four holes made for the steel pins in the male blocks of the joint were constrained using a pivot constraint as well as restricting all of the lateral movement. They were fixed to simulate the pins while permitting the necessary deformations. After applying all of the necessary constraints, the device was subject to a total force of 8500 N in the forward direction at the location where the tethers are located. Using the features within the CAD software Creo, contour plots were generated to demonstrate where the maximum stresses and deformations occurred on the during loading. Figure 47 displays the contour plot for the von Mises stresses.

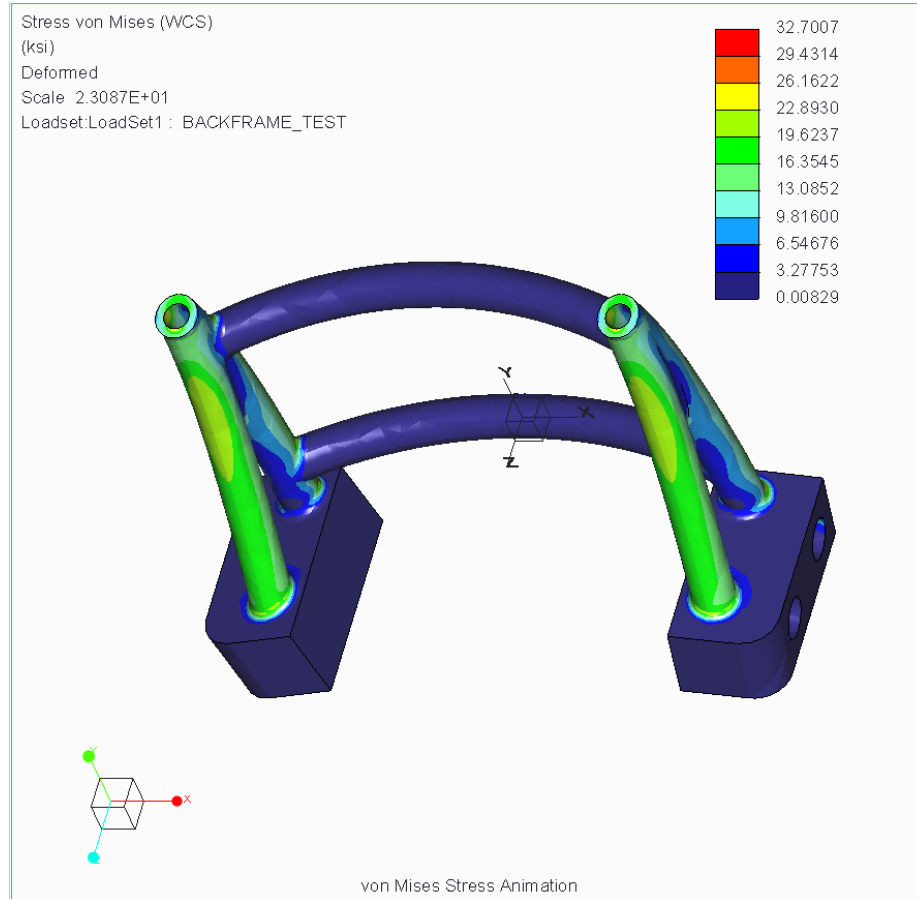


Figure 47. von Mises Plot of the Back Piece under Full Frontal Loading

Given that the loading involved in this problem is intended to be multi-axial, it is appropriate to assess whether or not the device fails when 8500 N is applied using the maximum von Mises stress. When the force was applied to the depicted region of the device, the contour plot showed that the maximum von Mises stress was about 32.7 ksi. The contour plot in Figure 47 displays the stresses experienced across the entire back region of the device and the male blocks. Since the force was applied to the topmost, posterior portion of the device, the maximum von Mises stress is found in that location. The schematic in Figure 48 shows this location in red.

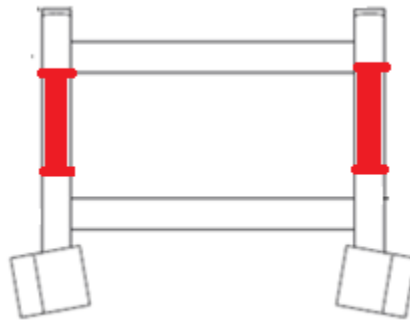


Figure 48. Posterior View of Back Portion of the Device

The device would not fail, fracture, or permanently deform under this loading as the von Mises stress is below the yield strength.

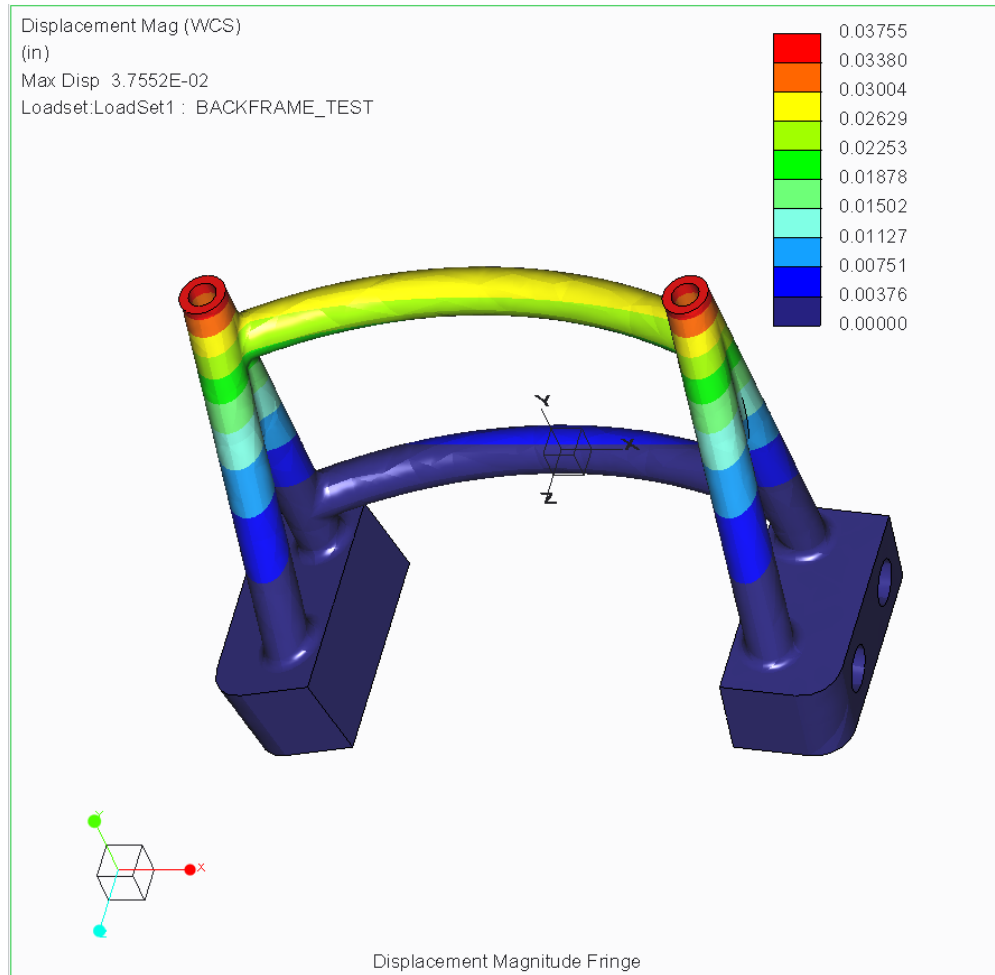


Figure 49. Displacement Plot of the Back Piece under Full Frontal Loading

Figure 49 shows the deflection of the back piece of the device while under full frontal loading. The maximum deflection occurred at the highest point of the back piece as that is the location where the force is applied to the device from head pulling on the HANS tethers, which equated to about .037 inches. The deflection experienced in the other portions of the back piece was significantly less due to the increased stability related to the presence of larger quantities of material. The small deflection experienced in the back piece is ideal for the purpose of limiting head movement in a crash.

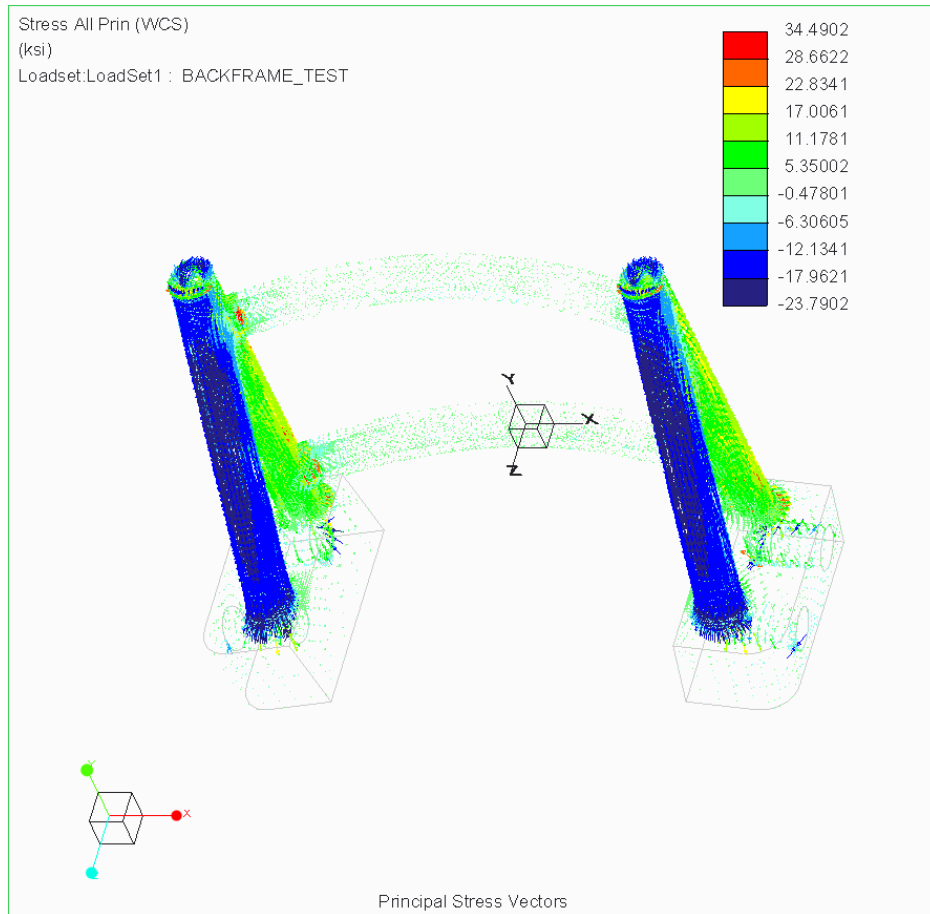


Figure 50. Principal Stress Plot of the Back Piece under Full Frontal Loading

Figure 50 depicts the principal stresses on the back region of the device while under frontal loading. As the maximum and minimum principal stresses experienced in the back region was 34.4 ksi and -23.7 ksi respectively, all of the principal stresses are below the ultimate tensile strength and the compressive strength, signifying that back piece of the device would be resistant to permanent deformation or failure.

8.3.2. Analysis of Female Block

Figure 51 shows the initial conditions previously calculated being applied to the CAD model of the female joint block. The orange arrows signify the loads applied from the pins, which both equal 16700 N as mentioned previously; the blue marks on the block define where the block is constrained, which is the location where the remainder of the wing is attached.

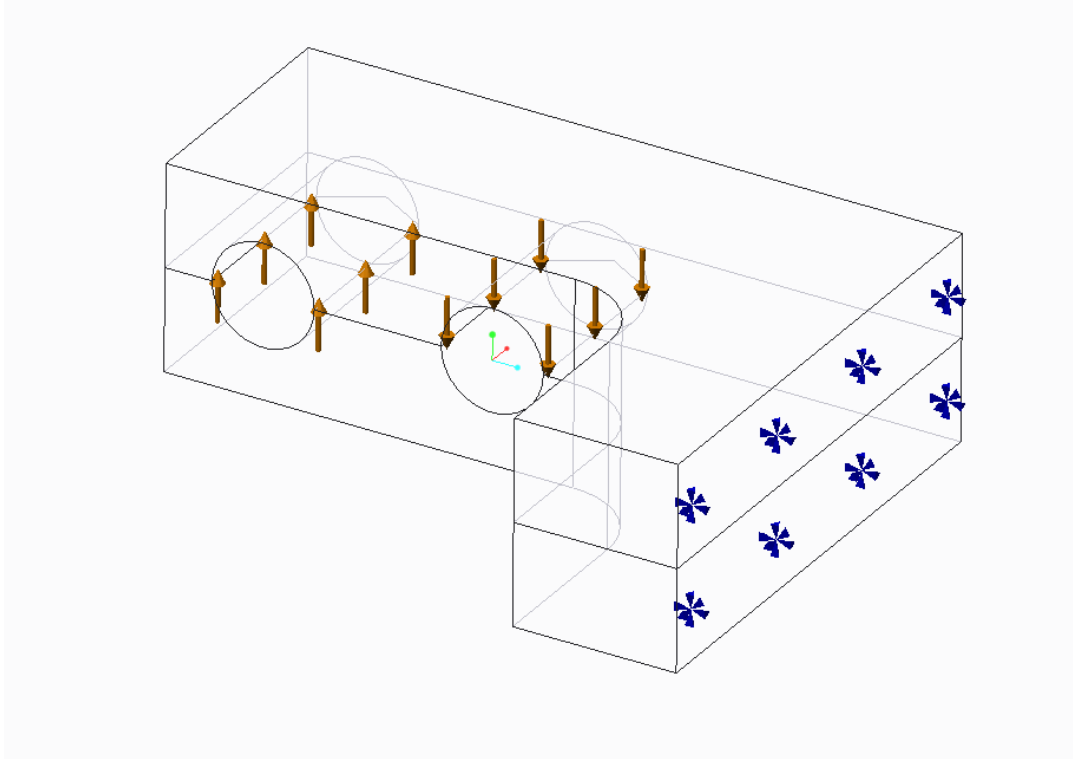


Figure 51. Female Block of the Joint with the Loads in Orange and the Constraints in Blue

After defining the associated loads and constraints, the simulation was carried out to assess if the loading generated stresses that exceeded the material's ultimate tensile strength. Figure 52 shows the von Mises stress plot for the female block when it is under frontal loading.

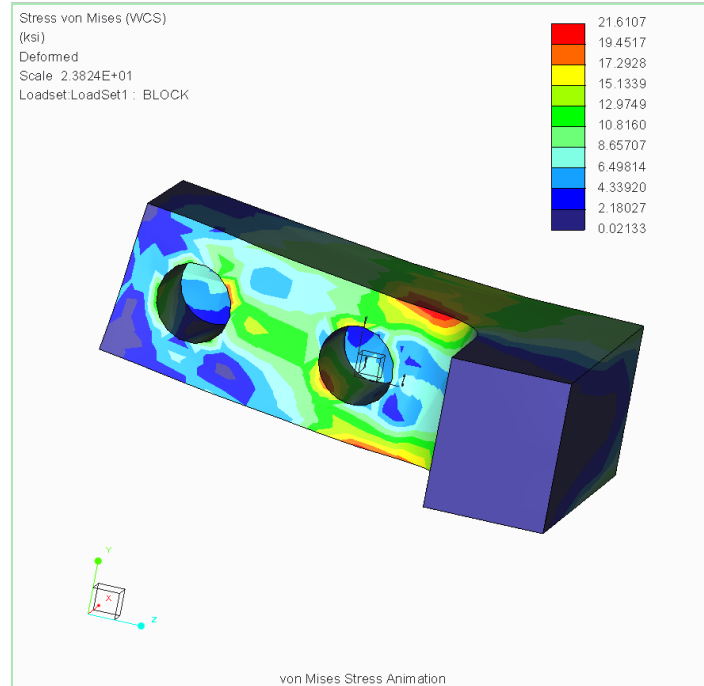


Figure 52. von Mises Stress Plot of the Female Block under Full Frontal Loading

The resulting plot demonstrates that the maximum von Mises stress experienced in the female block was approximately 21.6 ksi. Displayed as red in the contour plot, the maximum stress occurred near the hole closest to the constrained section. The stresses that transpired near the holes of the block were between 12.9 ksi and 15 ksi. The resulting von Mises stresses under the specified loading were well under the ultimate tensile strength and yield strength of 6061 aluminum, as the maximum von Mises stress is about one half of the yield strength.

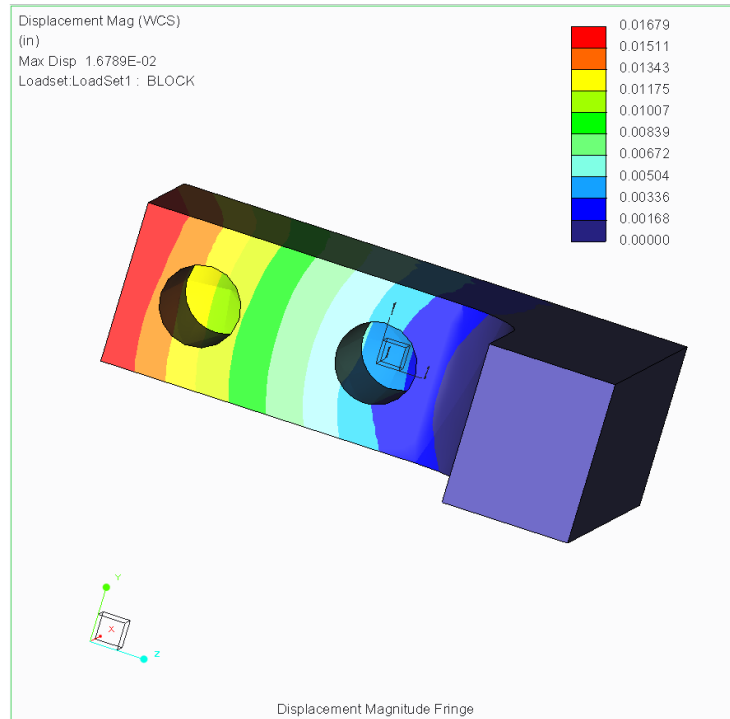


Figure 53. Displacement Plot of Female Block under Full Frontal Loading

Figure 53 shows the displacement plot of the female block when it is under the specified loading. The maximum displacement occurred at the left end of the female block and amounted to about .017 inches. Given the orientation of the block and the set constraints, the displacement experienced throughout the other portions of the block decreased progressively as the location of the constraint is approached. With the small amount of displacement that occurred from the determined loading, the joint of the device would not permanently deform in a crash, which is desirable since deformation to the joint could ensue future malfunction of the release mechanism.

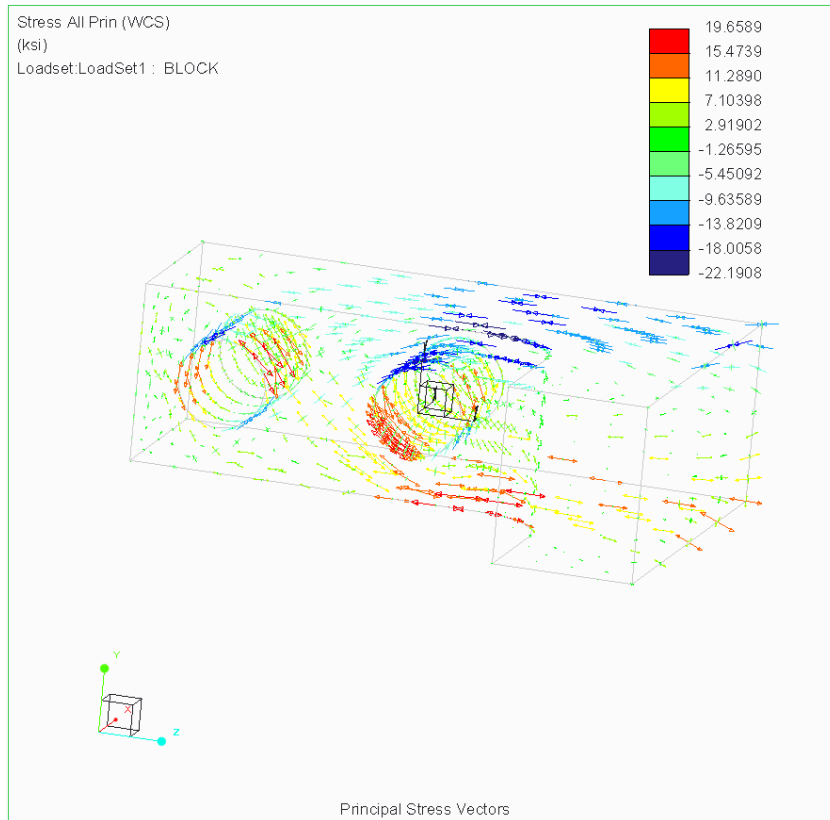


Figure 54. Principal Stress Plot of the Female Block under Full Frontal Loading

The plot of the principal stresses on the female block of the joint is shown in Figure 54. The maximum and minimum principal stresses were about 19.6 ksi and -22.1 ksi respectively, which are displayed as red and navy blue in the plot. Since both of the values for the stresses are below the tensile and compressive strengths of the material, the device will remain intact when it is loaded in a similar fashion as shown previously.

8.3.3. Analysis of the Pin

Assuming that the pins used for the joints are subjected to pure shear force, the calculated value of 16700 N can be used for each pin, which are .625” in diameter. The equations below show the calculations of the stress experienced by the pins.

$$Shear\ Stress = \frac{Load}{Area}$$

$$Area = \pi r^2 = \pi(7.9375)^2 \approx 198\ mm^2$$

$$Shear\ Stress = \frac{16700\ N}{198\ mm^2} \approx 84.4\ MPa \approx 12.2\ ksi$$

The stress experienced by the pins is well below the yield strength of steel, which is greater than 200 MPa. As with the other components, deformation of this part is undesirable in order to maintain the joint’s functionality. Since the stresses are less than half of the yield strength, this part should be considered for optimization for future revisions.

8.3.4. Whole Device Simulated Using the Compressive Force from Belt

Figure 55 displays a simplified free body diagram of the device while it is in use during a full frontal crash. The values shown in the figure represent the forces that were calculated previously.

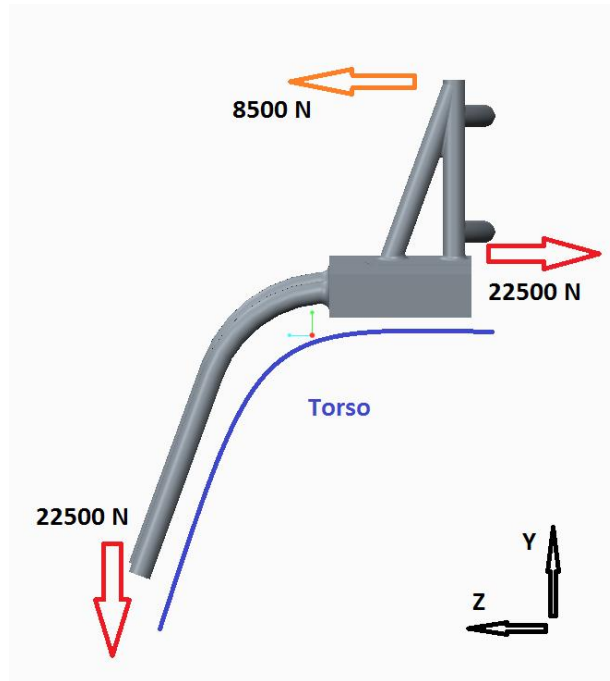


Figure 55. Simplified Free Body Diagram of the Device when Used during a Crash

The two forces of 22500 N in the negative y and negative z direction signify the force applied to the device by the belts of the restraints. The force in the positive z direction that equates to 8500 N represents the force applied to the back region of the device from the head. With this forces, a simulation in Creo was performed to test the device under the compressive loading from the belts during a crash. In order to perform the simulation, the constraints and forces had to be applied to the device. Considering that the user's torso would be applying a distributed force in the upward direction, the constraints were applied on the underside of the device; the constraints are shown in Figure 56 as blue triangles, while the forces from the belts and head are shown as purple arrows and orange arrows respectively.

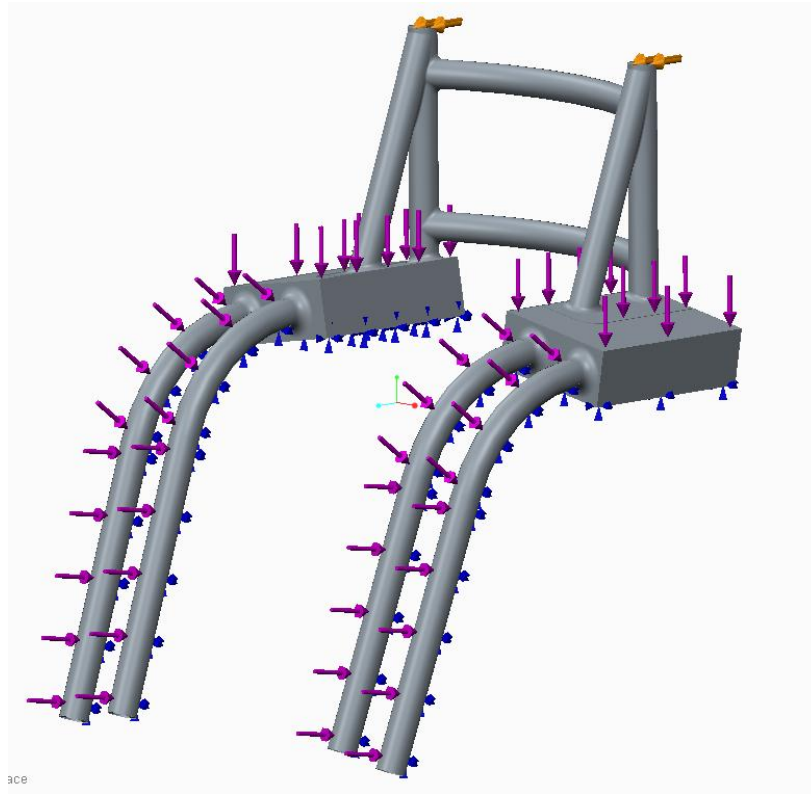


Figure 56. Forces and Constraints used for the Simulation where Purple Arrows represent the Distributed Force from the Belts, the Orange Arrows represent the Forces from the Head, and the Blue Triangles show the Constraints

With the forces and constraints assigned appropriately in Creo, the simulation was carried out, which generated three distinct plots: the von Mises stress plot, the displacement plot, and the principal stress plot. These plots are displayed in Figure 57, Figure 58, and Figure 59 respectively.

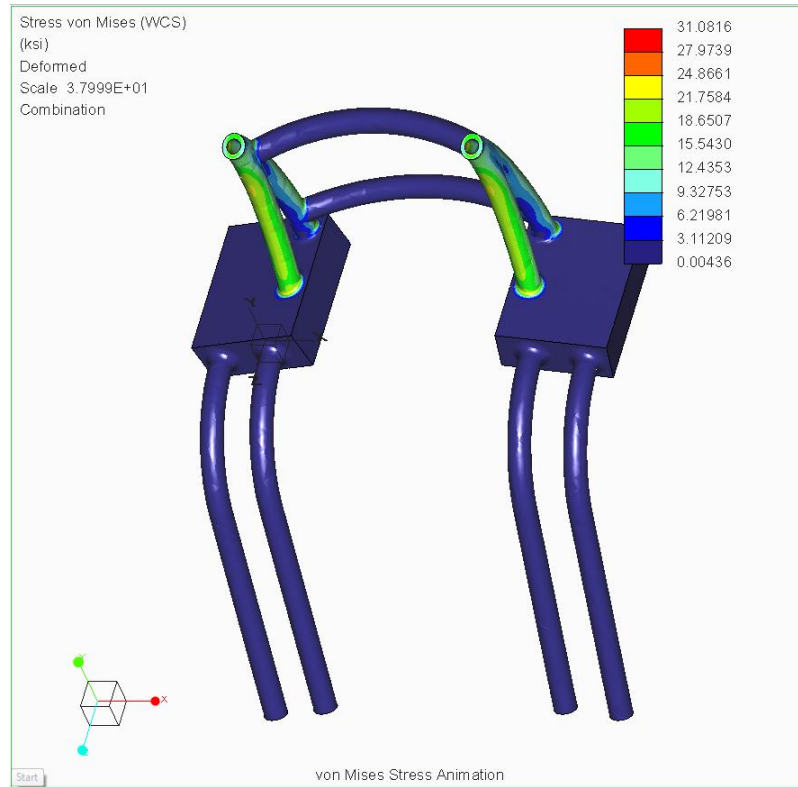


Figure 57. Plot of von Mises Stresses of the Entire Device under Full Frontal and Harness Loading

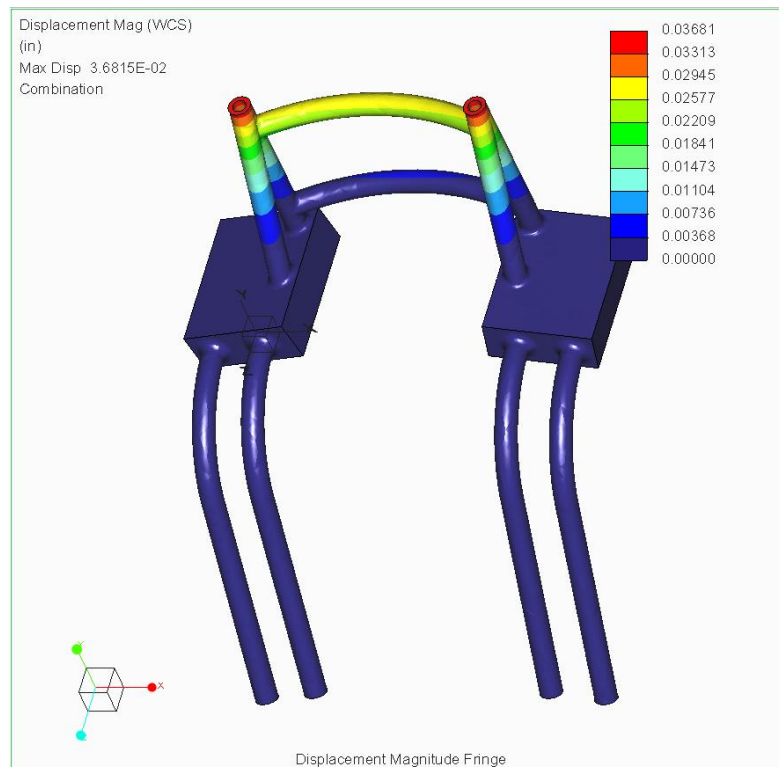


Figure 58. Displacement Plot of the Entire Device under Full Frontal and Harness Loading

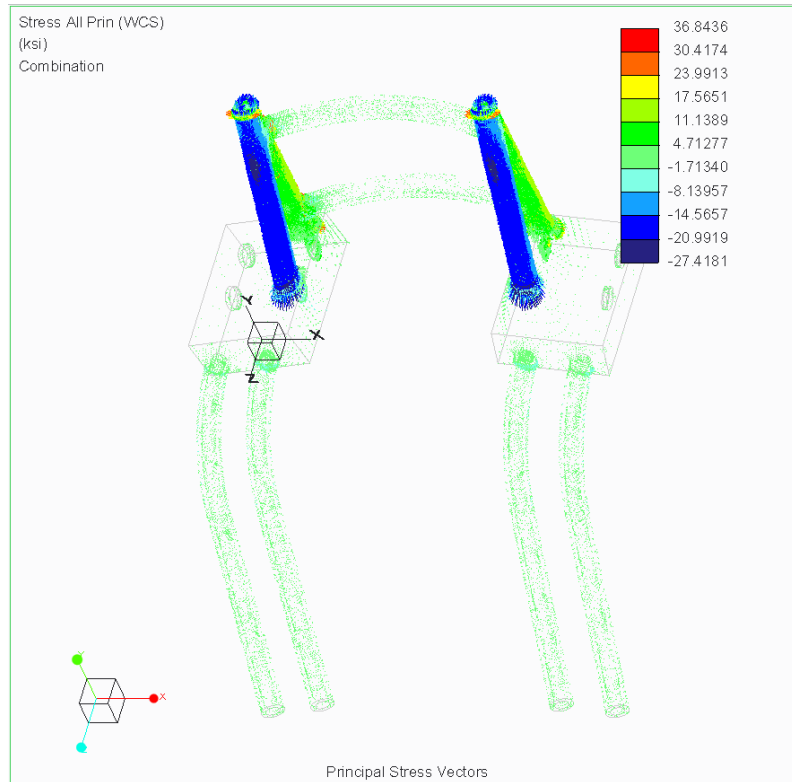


Figure 59. Principal Stress Plot of the Entire Device under Full Frontal and Harness Loading

After applying the predetermined forces, the von Mises plot showed that the maximum stress experienced throughout the device was about 31 ksi, which occurred on the back region of the device. The higher stress concentrations are displayed in green, yellow, and red in Figure 57. Similarly, the displacement plot shows that the maximum deflection also occurred on the back region of the device at the location where the forces from the head were applied. The maximum displacement amounted to about .037", which is relatively small, meaning that permanent deformation would not reside in the skeletal structure of the device. Figure 58 shows the portion of the device that experiences the maximum displacement in red. The last plot generated from the Creo simulation was the plot of the principal stresses, which shows that the maximum tensile and compressive stresses experienced within the device were 36.8 ksi and -27.4 ksi respectively. The maximum tensile stress, shown in red in Figure 59, occurred on the back part of the upper, back region of the device, while the maximum compressive strength, displayed as navy blue on the

plot, transpired on the front of the back region of the device. As the maximum von Mises stresses and the principal stresses did not exceed the ultimate tensile strength and ultimate compressive strength of the aluminum, the device would be able to withstand the applied forces without failing or deforming permanently.

8.4. Analysis of Latch

Since the only forces preventing the joint from sliding (and allowing the wings to separate from the device) are minute in comparison to the forces involved in a side impact, the usage of a mechanism that restricts lateral movement was required for appropriate securement. It was decided that a latch would be used to complete this task. A simple cam-sash latch that is typically used for windows in households can be used to release the wings from the back region of the device to permit easy removal. When used in conjunction with a tether, the latch can be opened quickly in the event of an emergency. According to SFI 38.1, a head and neck restraint must be tested at not only a head on crash, but at a 30-degree angle. In the case of that happening in a real life situation, the likelihood that the latch would break increases as a portion of the impact comes from the lateral direction. To determine the potential force that the latch needs to withstand, simple calculations were carried out using the values in Appendix B. The calculations are as follows:

$$total\ mass = m_{toptorso} + m_{bottomtorso} = 26.11\ kg + 2.5\ kg = 28.61\ kg$$

$$F_{torso} = ma = (28.61\ kg) \left(670 \frac{m}{s^2} \right) \approx 19000\ N$$

$$Force(30^\circ) = \sin(30^\circ) * force = 0.5 * 19000 = 9500N \approx 2136lbf$$

Figure 60 shows a schematic of the forces experienced by the driver on impact in a 30° frontal crash. The green triangle in the diagram is used to show the orientation of the crash with the red arrows the components of the 19000-N reaction force.

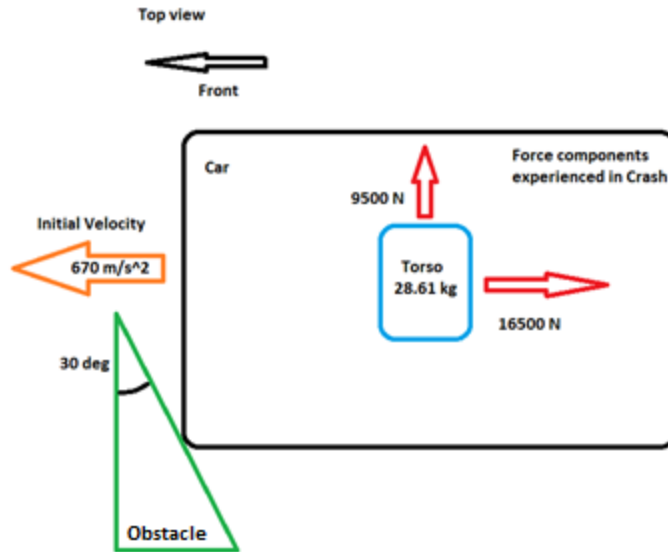


Figure 60. Schematic of the Forces acting on the Body of the Driver in a Crash from a 30° angle

Given that the maximum force that the latch could experience during a crash as described per SFI 38.1 can exceed 2,100 lbf, it was determined that an “off-the-shelf” latch may not suit the needs of the design. While latches have been found that are seemingly compact and withstand the forces in excess of 2,000 lbf, these products do not operate in a similar fashion to a cam-sash lock and they would inflate the cost for the manufacturing of the prototype. For demonstrational purposes, a set of latches were purchased and were used to demonstrate the action of opening the latch and separating the device; however, it is understood that this latch is not likely to withstand the extreme conditions witnessed in a crash. It was the intention to have a design specific latch modeled and evaluated, but manufacturing a latch of this nature was not feasible given the time constraints related to the project.

8.5. Improvements

Overall, the device is strong enough for a safety factor of 1.6; however, some parts should be considered for optimization to reduce the weight of the device and the cost in order to make the

device more comfortable and affordable for future users. The thickness and diameter of the joint blocks should be reduced. The shape of the joint block may also be shaped differently to improve the level of comfort while wearing the device. This would result in a slightly curved block rather than a rectangular block allowing it to contour around the pins at a given thickness.

9. Manufacturing the Final Design

Manufacturing the prototype of the final design included various processes including manual machining, welding, and applying fiberglass with specific techniques. Each step included in the development of the prototype was carefully thought out to produce a high quality product while using time efficiently. The following sections contain information regarding the methodology for manufacturing the final prototype.

9.1. Machining

The joint of the device was manufactured using a manual milling machine and a variety of tools. Due to the nature of the project requiring only small quantities of each part, a manual milling machine was chosen over a CNC machine, which is typically used for a larger volume of production. After the selection of the machinery to be used, a horizontal and vertical band saw was used to cut 6061 Aluminum into blocks with a thickness of approximately 1.25 inches and a width of 3 inches. After the aluminum was cut down to size, the block was then placed in the manual milling machine. An edge finder was spun in the machine at 800 RPM, and was used to locate the work piece in the machine. An Accurite Digital Read out was utilized to aid in the machining of the part. This displays the work coordinates of the machine and allows the user to move the machine to the desired location to the precision of 0.0001”.



Figure 61. 6061 Aluminum Stock after Rough Cut with the Band Saw

The blocks seen in Figure 61 were shaped to be 4" by 3" and 1/2" by 3" respectively. To form the 1/2" inside radii on the larger blocks, a 1" endmill that is depicted in Figure 62 was used. This allowed the part to be milled along the x and y directions until the desired shape was achieved with the radius in the corner. The matching outside radii on the 4" by 3" blocks were formed by using the rough shape on the vertical band saw and smoothing the surface to the correct size by using a large belt sander. This method was chosen as it would be problematic to form a perfect arc by moving the x-axis and the y-axis simultaneously.



Figure 62. Using a 1" End Mill in a Manual Lathe to shape the Contour of the Blocks

The holes for the pins were intentionally undersized, so they could be secured via a press fit. The .625” steel dowel pins were pressed into the aluminum block using a large arbor press located in the Higgins Machine Shop. Figure 63 displays the finished joint.

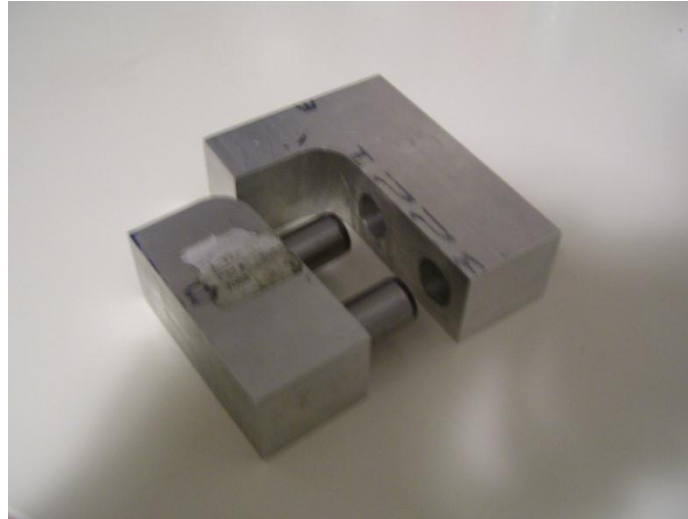


Figure 63. Finished Joint

Following this step, the 6061 Aluminum tubes of .625” diameter with a wall thickness of .125” were cut to the appropriate length on a horizontal band saw. The tubing was then notched to predetermined angles using the milling machine and a .625” end mill. This notching of the tubing provides for a clean fit for the bars at each joint permitting for easy welding.

9.2. Welding

The device was welded together using a Miller Syncrowave, Tungsten Inert Gas (TIG) welder. Pure tungsten was used along with ER4043 3/32” filler rod. After the device was welded, the holes for the latches and tethers were drilled and tapped for proper location. They were then affixed to the device during final assembly. Figure 64 shows the skeletal structure after being fully welded.



Figure 64. Skeleton Structure After Being Fully Welded

9.3. Shell

The fiberglass shell of the device was made by taking foamboard, typically used for insulation in construction, and shaping it to the desired form using a rasp. The foam was covered with painters tape to prevent it from melting when the resin was applied.

Next, sections of fiberglass sheet were cut to size and fit to the core structure to confirm they would cover the device. The resin was mixed with hardener and applied to the device, followed by the first layer of fiberglass mat. The layer of mat was again covered with resin to ensure it was properly affixed. After drying, a second layer was applied using another batch of resin and fiberglass sheet.

The device was sanded to remove all of the flaws on the surface and auto-body filler was applied to fill-in any imperfections in the finish. The process was then repeated; any of the final blemishes were coated with filler and sanded once more before the device was spray-painted.



Figure 65. Completed Prototype

Lastly, the device was then painted with several coats of high gloss, black paint for the final finish. Figure 65 depicts the completed first generation prototype of the device.

9.4. Helmet



Figure 66. TMS Helmet Purchased from Amazon (Matte Black – Amazon)

The helmet, depicted in Figure 66, was ordered from Amazon and was promptly outfitted with HANS anchors and quick releases. This required the team to layout the positions on the helmet per the instructions provided, and drill the helmet's shell with at 1/4" drill bit. The anchors were then bolted to the helmet using the provided hardware.

10. Test Procedures

The overall goal of testing the prototype was to determine if it was quicker to remove the newly designed device by releasing a wing via the quick release latch than to remove a traditional style head and neck restraint. A group of volunteers from WPI's student body performed a series of three tests, so that time data could be collected for future statistical analysis. Testing also would allow the team to observe if inexperienced volunteers encountered any significant problems while removing the device.

Prior to testing the device, each participant was asked to sign a waiver that informed the test subjects that the testing would be recorded via camera to collect time data and no personal data would be recorded. Additionally, by signing the form, the participant agreed not to discuss or divulge any information regarding the device with anyone outside of the project. The waiver read as follows:

Release for video recording during testing:

The testing of the device will include 3 different trials, all of which will be recorded digitally. This video is merely so the MQP group can record times from the trials and acquires data from the video which may have been missed when the trials were performed live. No information from testing (age, height, name, etc) will be released. This is merely for statistical analysis. The video recordings will be deleted/destroyed upon completion of the MQP.

Non-disclosure: I also agree not to discuss or divulge any information regarding this device, as a whole or in parts, or how it functions, as this is sensitive information.

By signing the following, I have read and understand the terms of this agreement.

Name (Printed): _____

Signature: _____ Date: _____

After the form was signed, each participant was provided with a specific explanation regarding the prototype and the mock cockpit via verbal instructions and visual demonstration, which included a detailed description of each of the three tests. Also, he (or she) was given five minutes to practice each task and become acquainted with the device before the official trial, so the design team could obtain accurate data.

Then, the participant was strapped into a Society of Automotive Engineers (SAE) Formula car that was equipped with a five-point racing harness with three-inch belts in the Washburn Machine Shop located on campus. Upon the appropriate positions of the lap belt, the prototype was placed on the shoulders of the participant, and the shoulder belts were guided over the wings of the device and secured into the latch of the harness on the lap belt. The volunteer then put on the helmet that had HANS tether anchors attached to the sides so that it could be used in conjunction with the prototype. A member of the design team assisted the volunteer in connecting the HANS quick releases to the anchors on the helmet. At that point, the participant was ready to proceed with the three tasks involved with testing the device. The three tasks that each participant performed were:

1. Releasing the latch for the harness and standing up without removing the device or the helmet. This test mimics the method of exiting the car with the use of a conventional HANS device, as they normally do not remove it when in an emergency. This purpose of this test was for the participant to become accustomed to the environment and the general procedure.
2. Releasing the latch for the harness, releasing the HANS quick releases attached to the helmet, and removing the prototype as a whole component and standing up without removing the helmet. This test simulates the method that drivers utilize to remove the HANS device if they are not in danger or if they encounter extreme difficulty exiting the car.
3. Releasing the latch for the harness, releasing the HANS quick releases attached to the helmet, releasing the latches on the wing based on the dominant hand (meaning left-handed people would use the left latch and right-handed people would use the right latch),

removing the device in separate pieces, and standing up without removing the helmet. A detailed instruction manual for the prototype is located in Appendix G.

When all of the trials were completed, data were collected regarding each participant's gender, age, height, and experience with racing safety equipment. Also, the group asked each subject their level of comfort while wearing the device based on a five point scale: one being extremely uncomfortable to five being extremely comfortable. Table 7 contains information that defines the significance of each number for assessing the comfort of the device.

Table 7. Five Point Scale for Comfort Assessment

Number	Assessment
1	Extremely Uncomfortable
2	Slightly Uncomfortable
3	Neither Comfortable or Uncomfortable
4	Slightly Comfortable
5	Extremely Comfortable

Lastly, each participant was asked to provide any comments regarding the testing experience and any suggestions for renovations to the prototype. The document used to record this information about each participant appeared as follows:

WPI Motorsports Safety MQP Testing Document

Participant ID:

Gender: Male or Female (Circle one)

Age:

Height:

Prior (relevant) experience using racing safety equipment: Yes or No (Circle one)

Comfort: 1 2 3 4 5 (Circle one)

Test 1: Exit racecar leaving both helmet and head and neck restraint on:

Time:

Comments:

Test 2: Exit racecar leaving helmet on and removing device as a whole

Time:

Comments:

Test 3: Exit racecar leaving helmet on and removing device in separated pieces.

Time:

Comments:

The commentary recorded on these documents was used to assess where improvements could be made in future iterations of the prototype.

11. Results

A total of 11 people tested the prototype including the three members of the Major Qualifying Project group. The sample population included three females and eight males between the ages of 18 and 25. Among the test participants, only three males had racing experience. The average height of the sample population was 66.8 inches, or just under 5'7". After each person performed each of the three tasks, the group collected the time data from all the videos and destroyed the videos immediately. For each trial, the time started from the point that the participant touched the release for the harness and ended when he (or she) stood up. Table 8 contains all of the time data in seconds for the 11 participants.

Table 8. Time Data from Testing the Prototype

ID #	Test 1 – No Removal/Stand Up (s)	Test 2 – Removal similar to Traditional Devices/Stand Up(s)	Test 3 – Removal via Quick Release (s)
1	3.02	10.42	10.13
2	3.8	14.2	10.2
3	6	15.1	12.4
4	4.66	12.68	13.5
5	4.24	13.04	9.22
6	8.02	12.16	11.6
7	9.5	13.9	11.9
8	8.7	28.9	22.9
9	2.91	8.28	6.84
10	5.34	9.34	6.68
11	1.95	9.5	8.57

As the purpose of the testing was to compare the times of the tests involving removing the device as a whole and removing the device utilizing at least one of the quick release latches, the difference between Test #2 and Test #3 was determined for each participant. Table 9 contains the difference between the times related to the trials involving the removal of the device for each participant.

Table 9. Calculated Time Differences between the Test involving the Removal of the Prototype as a Whole Component and the Test involving the Removal of the Prototype via a Quick Release Latch

ID #	Time Difference (s)
1	0.29
2	4
3	2.7
4	-0.82
5	3.82
6	0.56
7	2
8	6
9	1.44
10	2.66
11	0.93

The average time difference for this data set was 2.14 seconds. The other value that was calculated using the data was the standard deviation. For this set of data, the standard deviation was approximately 1.96 seconds. Appendix H shows the formulas and methods used to calculate these values.

Table 10 contains the data regarding each participant's level of comfort while wearing the device using the five-point scale mentioned previously.

Table 10. Participants Evaluation of Comfort using Scale with 1 being Extremely Uncomfortable and 5 being Extremely Comfortable

ID #	Level of Comfort
1	3
2	2
3	3
4	3
5	4
6	3
7	3
8	4
9	4
10	4
11	4

Based on the sample size of 11 participants, the average comfort level was 3.36, which signifies that the majority of population did not find the device to be extraordinarily uncomfortable.

12. Data Analysis and Discussion

The following sections discuss the results from tests conducted using with a group of volunteers, a statistical analysis of the collected data, and a brief assessment of whether the final prototype met all of the design specifications or not. The purpose of this process was to determine how well the device met the original design specifications in addition to the first generation prototype's overall functionality.

12.1. Discussion of Experimental Testing

After the participants finished the three separate tests, the design team recorded observations regarding any difficulties or unique events that transpired during one of the trials. Based on the team's observations, a majority of the volunteers encountered problems when it came to releasing the HANS tethers that attached to the helmet. The two issues related to the HANS tethers that frequently occurred during testing were that one of the HANS quick releases while the other remained attached to the helmet or both remained attached to the helmet after the tethers were pulled. When either of these issues occurred during a trial, the participant was asked to restart the trial from the beginning. In the group of eleven participants, five participants had trouble with these helmet tethers. Once the participants were able to release the HANS quick releases, all participants were able to proceed with the following steps of the trial. When removing the device as a whole component to simulate removing a traditional head and neck restraint, participants had to lean forward in the cockpit so they could remove the device completely. All of the participants encountered difficulty removing the device as a whole component while wearing a helmet. Considering the device could not be lifted directly over the helmet, participants used two different strategies to remove the intact prototype. The first strategy that was observed by the design team was that some participants rotated the device so the back

frame was one of their shoulders and then removed the device from their side. The other strategy that was utilized involved volunteers reaching behind their head and removing the device, which caused discomfort and difficulty given the arm motion required to remove the prototype using this method. Regardless of the method that was utilized, all of the participants encountered some difficulty when removing the device as a whole component, which resulted in a higher time for that trial. When removing the device via one of the latches, most volunteers were able to release the wing in one swift motion. No significant problems occurred with removing the wing until a participant who had prior racing experience tossed the prototype aside with a large amount of force as if he would if he were in danger. After this trial, the right wing was extremely difficult to remove as the pins could have bent slightly when the prototype hit the ground. Members of the design team then practiced removing the device with the right latch and found that adjustments would have to be made to the device. However, given the time constraint, the remaining two participants were informed to use the left latch to remove the device as the right one would most likely malfunction. Although the left latch had to be manufactured by the design team as left-handed window latches were not readily available, the latch released easily when the tether was pulled even without a cam mechanism integrated into the latch.

To obtain additional feedback, the team asked each participant if he (or she) had any comments about the device or about the whole testing experience. As the design team observed from the videos and in person, almost half of the participants reported that it was difficult to assess whether the HANS quick releases actually separated from the anchors on the helmet. Most of the comments the team received pertaining to the prototype device revolved around the location of the tethers utilized to release the latch located on the wing. One volunteer suggested that the tether should not be located under the belt as it was slightly difficult to determine where it

was during the trial. Other participants noted that the location of the tether when attached to the Velcro on the wing was awkward and should involve thicker material, so the tether can be detected faster. Also, a few volunteers recommended that the tethers be directly attached to the belts of the harness. The last of the comments included one participant proposing that the device should be more fitted to the body in addition to the weight being reduced as he felt a noticeable amount of pressure near his collarbone.

12.2. Data Analysis

A statistical analysis was performed using the time data collected from the video footage to compare the data as means of determining if the time to remove the device by releasing a wing via a quick release latch was significantly less than the time to remove the device as a whole component. To execute this analysis properly, prior assumptions regarding the control group and other factors had to be clearly defined to avoid any confusion in the future. As a result, considering that it was expected that each individual that participated in the test process had varying degrees of skill, each individual acted as his (or her) own control group to provide a useable basis for sufficient analysis. This indicated that the data that would be analyzed would be the difference between the time it took to remove the device as a whole and the time it took to remove the device using one of the quick release latches per individual. With the differences calculated for each volunteer, a mean difference could then be calculated to obtain a mean of the sample population. Thus, a matched pair one-tailed T-test would be utilized to determine if the data was statistically significant.

Before any calculations were made, the null and alternative hypotheses were devised based on the assumption that it would take less time to remove the prototype using one of the latches than the time it would take to remove the device as a whole component. In terms of the

difference between the times for the two tests, the null hypothesis was that the mean difference between the two tests was equal to zero, meaning that there was no difference in the time to remove the device using the two methods. The alternative hypothesis was generated by the team and compared to the null hypothesis was that the difference between the time to take off the device without using the latch and the time to take off the device using a latch is greater than zero. The significance of the alternative hypothesis is that it would take less time to remove the prototype with the use of at least one latch. The P-value selected for this test was .05 as that is the typical value used to determine statistical significance. Given, the number of volunteers, the degrees of freedom (DOF) for this test is defined as 10. The last piece of information that had to be defined prior to carrying out the test was the rejection criteria. Given the characteristics of the alternative hypothesis incorporating the difference being greater than zero, the null hypothesis could then be rejected if the calculated test statistic was greater than the critical value attained via a distribution chart.

From the data, the mean time difference was calculated to be 2.143 seconds as mentioned previously. Additionally, the standard deviation to be used in this T-test was 1.96 seconds. With the mean of the sample population, the standard deviation, and the number of participants, the test statistic T was calculated to be 3.457. Using the degrees of freedom and the P-value, the critical value was determined to be 1.8124 from the T distribution Critical Values table (Johnson, 1992). Since the test statistic of 3.457 is greater than the critical value of 1.8124, the null hypothesis can be rejected for the alternative hypothesis based on the defined rejection criteria. The rejection of the null hypothesis implied that the mean difference between the times of the two tasks performed during testing was statistically significant. Therefore, the matched-pair T-test provided the necessary clarification that the implementation of joints into the prototype was beneficial in the

sense that the time to remove the device decreased in comparison to the time to remove a current head and neck restraint. Appendix H contains all of the formulas and calculations used to perform the matched pair t-test.

12.3. Design Specification Assessment

After testing the device, the design specifications that were formulated at the beginning stages of this Major Qualifying Project were assessed to see how well the device met them. The first specification stated that the device must cost less than \$750; however, the economic analysis located in Appendix I demonstrates that the device would cost about \$1100. Considering that the design of the prototype included an additional feature, it should have been anticipated that the cost of the device would be higher than the current devices on the market; however, it is still less than the most expensive device featured in Table 1, which describes the characteristics of current head and neck restraints. Although the proposed cost was over the specified cost, the price of future iterations would be significantly less as the materials would be purchased in mass quantities, which would reduce the cost per device. The second design specification involved the weight of the device being less than three pounds. This specification was not met, as the final prototype weighed 5.5 pounds. Through assessment, specific modifications could be made to reduce the weight of the device, which are highlighted Chapter 15.

Some of the design specifications were evaluated directly through the testing procedures mentioned in Chapter 10. One of the specifications declared that the device must be able to be removed within five seconds or less in a non-crash-like situation. Given that time data were recorded for each trial, the prototype was removed in five seconds or less in all cases. However, the data does not show this phenomenon as the trial incorporated additional steps other than

removing the device. Another specification that was satisfied through the tests was the ability to attach to SAH2010 style racing helmets featuring pre-drilled mounting holes. As HANS quick releases were secured onto the prototype and the anchors were attached to the helmet, the prototype was able to attach and work in conjunction with the helmet during all of the trials. The design specification mentioning the device not interfering with a five- or six-point racing belt harness was also met as the tests involved a mock cockpit that included a five-point harness. The only concern regarding the harness was that the quick release latches featured on the prototype could cause the belts of the harness to move out of position under the driving conditions during a race. Given that the featured quick release latches are attached on top of the base structure, the belts of the harness could slide off the driver's shoulders, which could affect the functionality of the five- or six-point harness. Therefore, additional tests could be performed to assure that the belts would remain stationary on the shoulders of the driver. The specification regarding the device not obstructing the vision of the user was also met as each member of the group along with the test subjects did not mention or complain about problems associated with sight while wearing the device. The last specification that was affirmed through the test procedures was that it was able to be cleaned using simple household cleaning products, as the device and helmet were cleaned with generic disinfectant spray after each user for sanitary purposes.

Although the final prototype met most of the specifications, a few of the specifications were not properly assessed given the constraints related to the project. One specification that was not assessed was the device's functionality in temperatures ranging from 20°F to 135°F. Despite the fact that no tests were performed in different climates and environments, the aluminum structure would be durable within lower and higher temperature climates. Additionally, the prototype was not subjected to extreme temperatures or flames, as the SFI Specification 38.1

requires for approval. Therefore, it cannot be definitively stated whether or not the device would be SFI certified without proving that the device is flame resistant. As a result, further testing and assessment are needed to determine if these specifications were met.

13. Conclusion

Given the prevalence of neck injuries and basilar skull fractures in motorsports, head and neck restraints have been mandated in most top-tier racing divisions. Case studies from renowned drivers demonstrated that the current head and neck restraints often inhibited their ability to escape the car in a crash-like or dangerous situation that could jeopardize their well-being. As a result, the goal of this project was to design and build a prototype for a head and neck restraint that can be removed easily while wearing a helmet to facilitate exiting a car in an emergency such as a fire or situation where emergency medical personnel need to put a brace on the driver's neck.

After design specifications were generated for the project, various design alternatives were produced that involved unique methods of separation to permit its removal prior to exiting a racecar. Evaluation of the preliminary designs revealed that the final design would consist of three substructures: the skeleton, the joint, and the core. The base structure, or the skeleton, was shaped like most head and neck restraints, but was manufactured from aluminum instead of solely carbon fiber. To allow removal from either the right or left side, two pin joints that permitted only one degree of freedom were implemented into the final design, so the wing portions of the device could be removed as easily as possible without affecting the integrity of the device. Latches with connected tethers were used to restrict lateral movement of the wings and to assist the removal of the wing. The core, or body, of the prototype was formed around the skeleton with the use of foam, several layers of fiberglass, resin, and hardener.

Testing the device with volunteers showed that it took less time to remove the device with the use of at least one of the quick release latches than it did to remove the device as a whole component. Even though the testing of the prototype provided evidence that the method of removing the head and neck restraint was successful, there were some issues related to the release

of the wing, such as locating the appropriate tether and pulling the tether attached to the quick release at the appropriate angle. The only other significant problem related to the prototype was the final weight of the device as it was over five pounds. Keeping the device at the current weight could cause severe discomfort for drivers when wearing the device for long periods during a racing competition.

Considering not all of the design specifications were met, additional testing, including physical testing of the joint and several other methods of testing, would be necessary to determine if the device would remain structurally intact during a high-speed crash. It is recommended that a second-generation prototype should incorporate more efficient release mechanisms to remove the wings easily and less material to reduce the overall weight to improve upon the first generation prototype, which was constructed to demonstrate the proof-of-concept.

14. Interviews with Professional Racecar Drivers

Given the available resources and contacts, the group was able to meet with two people, Jean Paul Cyr and Ray Dona, each of whom had multiple years of racing experience. The subsequent sections summarize the happenings of both consultations.

14.1. Interview with Jean Paul Cyr

One of the members of the group met with Jean Paul Cyr, a seven-time American-Canadian Tour (ACT) champion, who races in the late model sportsmen division involving closed cockpit cars. As the ACT does not require head and neck restraints, Cyr was one of the last drivers in the series to use this form of protective device. Due to a previous injury, the ACT champion encountered difficulty when selecting a head and neck restraint, because he needed a device that provided him with the most comfort and one that would not irritate the injured area. This caused him to select the Hutchens device opposed to the HANS device originally, as he was afraid the HANS device would inhibit his ability to exit the car quickly. Cyr's main fear was that the HANS device would cause him to be trapped in the car in the case of a fire. Despite his initial fears, Cyr switched to using a HANS device. Since his first usage of the HANS device, he felt as though the tethers restricting the forward movement of the head have reached their limit, which indicates the severity of the crashes that he has experienced. He also stated that he now refuses to enter the track for even a practice if he feels the tethers are not capable of performing adequately.

Since the group member brought the prototype of the new design to the meeting, Cyr provided a few valuable comments and suggestions based on his observations. First, he asserted that the group's device was overdesigned. Although he did not weigh either the HANS or the prototype, he noted that the device the group produced was heavy, whereas the HANS he uses weighs only a couple of pounds. Upon further examination, Cyr was concerned that the back of

the device could still become caught on the roll bar, or roll cage; an example of a roll cage is depicted in Figure 67.



Figure 67. Roll Cage Installed in a Closed Cockpit Car (Cage This)

However, Cyr was unaware that the group prototype featured HANS quick releases, unlike his HANS, which features fixed tethers. To release fixed tethers, the driver must reach up and unclip the tether manually from the helmet, whereas the quick release tethers feature a pull cord to release them quickly. Without quick release tethers, the yoke of the device would continue to stay attached to the helmet, unless the driver released it manually, rendering the release of the wings pointless. From this, it was noted that the group's device would only function as intended if the user buys the quick disconnects manufactured by HANS. Additionally, Cyr offered several suggestions on how the device could be commercially produced in an easier fashion. The options he proposed included having a recess for the latch, a pinned detent handle, or a hinged design as he mentioned that belts passing over the existing prototype might be problematic. Recessing the joint would entail an additional cut into the skeleton of the device that would allow the latch to be mounted below the surface to minimize any interference with the belts. Figure 68 and Figure 69 depict a recessed joint in the closed position and open position respectively.

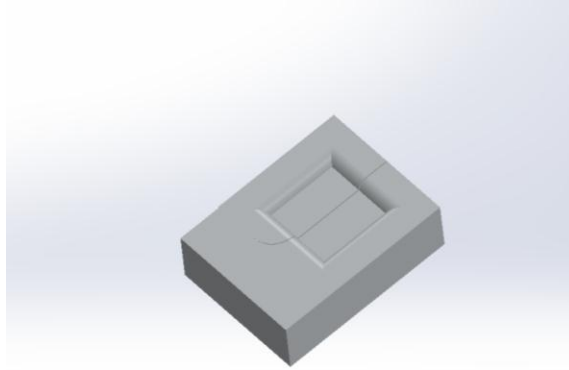


Figure 68. Recessed Joint Shown in the Closed Position Detailing the Location for the Latch

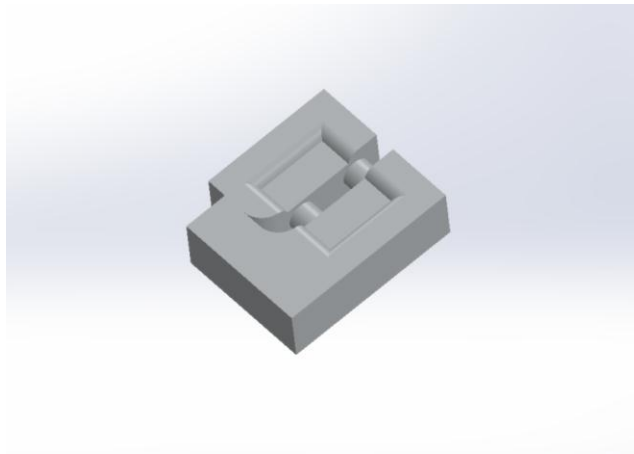


Figure 69. Separated Recessed Joint

A detent pin is simply a pin that features a spring-loaded ball bearing that would interface with the joint of the device and prevent the joint sections from separating. The pin would be fixed to the wing or outer joint. The two sections would be less likely to separate, as the ball bearing detent will need to be pushed in before the device would separate by simply pulling the pin out of the joint. The d-ring on the pin is useful in the sense that the tether can be appropriately placed on it to allow for easy removal of the wing. A tether connected to this pin would be pulled away from the body to release the wings, which would allow the motion of the user's arms to be in line with his (or her) shoulder. This method of restricting the lateral motion of the joint when the

device is in use would reduce the amount of force required to remove a wing and would not incorporate any movements that oppose any natural, kinematic movement of the arm.



Figure 70. Detent Pin with a D-ring for a Tether

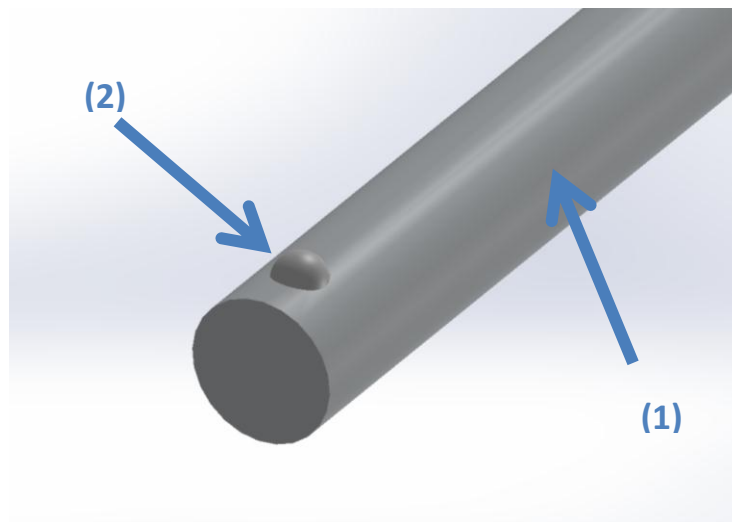


Figure 71. Detent Pin (1) detailing the Spring-Loaded Ball Bearing (2) that Prevents Unintended Movement

Figure 70 shows an example of a detent pin with a D-ring to attach a tether. Figure 71 depicts a close-up of the detent pin showing the spring-loaded ball bearing that functions to prevent any

unintended movement. The (1) annotated in the picture is pointing to the cylindrical body of the detent pin, while the (2) annotated in the figure is pointing to the spring-loaded ball bearing built into the pin. The block portion of the device with the detent pin restricting lateral movement is depicted in Figure 72, while Figure 73 shows the block in a separated orientation with the detent pin.

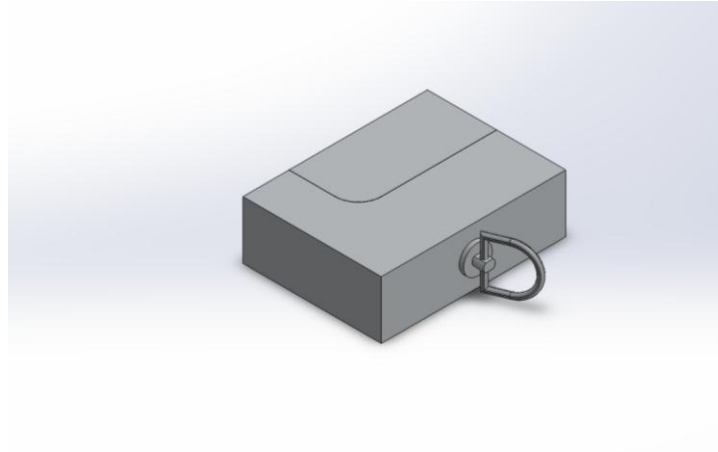


Figure 72. Detent Pin and Block Assembly

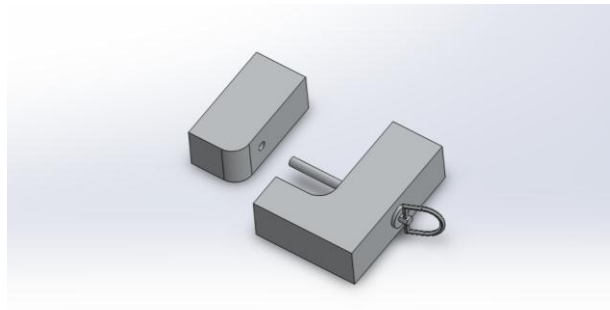


Figure 73. Separated Block with Detent Pin

Overall, Cyr felt that the design was a good idea and would certainly be marketable given that design changes were made to ensure that the belts of the harness remain secure on the driver's shoulders.

14.2. Interview with Ray Dona

All three members of the group were able to meet with Ray Dona from Berlin Massachusetts, who has had 20+ years of experience racing Formula 5 cars and is self-employed as an engineer. Upon the group's arrival, Dona reported that he has tried multiple head and neck restraints, such as the HANS device and the NecksGen, but has had a few problems with each of the devices. First, he mentioned that the both devices inhibited his ability to move his head from side-to-side, which could affect his driving. The other comment he had about both devices is that belts of the harness often slide off the wings of the HANS device or the NecksGen due to the orientation and thickness of the wings. Since the harness was causing him problems during official races, Dona decided to use an additional Velcro strap to restrict the lateral movement of the belts. Since he had a HANS device available, he demonstrated the problems he briefly described while in the cockpit of his car. Figure 74a and Figure 74b display Dona wearing the HANS device with and without the additional Velcro strap respectively. The orange arrow in Figure 74b shows the location of the addition strap when in use.

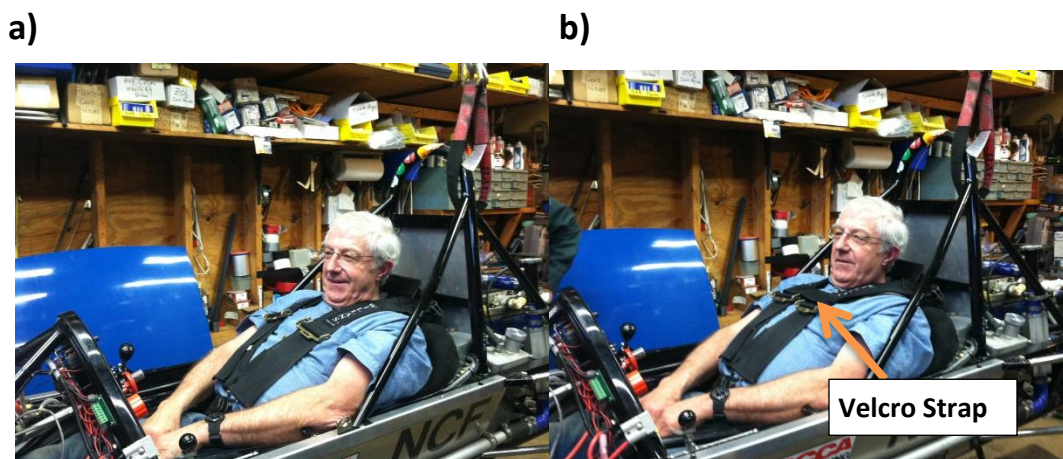


Figure 74 a) Dona with the HANS device. b) Dona with HANS device and Additional Strap on Harness

After mentioning the problems he had with existing head and neck restraints, Dona examined the group's device and seemed immediately fascinated with the first generation

prototype. Once one of the group members described the purpose of the prototype, Dona offered to test the device in one of his cars. Figure 75 shows Dona in his car, while wearing the prototype.



Figure 75. Ray Dona with the Prototype

Once he was strapped into the car, he noticed that the belts of the harness were not falling off the device as the width and shape of the wings differed from the existing products. He also mentioned that the wings were very straight and should be more contoured to the body. The other option he suggested was to implement wings that can be adjusted to different angles to accommodate different body types. Another comment he had was that the HANS tethers attached to the helmet needed to be able to slide to provide the head with a larger range of rotational motion. The group asked Dona if he would attempt to remove the device using the latches after a brief set of instructions. Given the angle of the seat and the components of the car on the sides, he found that it was difficult to remove the latch unless he moved his torso forward slightly. Figure 76 displays the side frame of the car that obstructs the motion involved in removing the wing of the device.



Figure 76. Close Up View of Dona Pulling Tether

Throughout his attempts to remove the wings, he was able to undo the latch on the right side; however, the wing would not come off easily. The difficulty Dona faced when attempting to remove the right wing transpired, because the students that tested the device all used the latch on the right side to remove the device. Since the right side of the device had been repeatedly removed, the coating used to reduce the friction between the steel pins and the wings worn off, causing the joint of the device to bind during use. After a few attempts, Dona then tried to remove the left wing, and found that the latch manufactured by the group functioned as intended. Lastly, while Dona understood that the device presented was a proof of concept, he advised that an alternative latch be used. An alternative latch would prevent any issues with the latch being caught in the belts, since the current latches protrude off the device and have the tendency to become entangled with the safety harness. After using the device for a short period, Dona believed the concept behind the group's prototype was valid and that the group should proceed with the steps towards presenting the idea to others.

15. Recommendations

With the understanding that the manufactured device of the selected final design was a first generation prototype to display the proof of concept, specific changes would be recommended for future iterations in terms of the weight, type of latch, molding method, and other minor alterations. By implementing such changes, the product would become more marketable to the racing population as its functionality, relative comfort, and appearance would improve greatly.

15.1. Weight Reduction

The weight of the skeleton evaluated in Creo was 4.73 pounds, but the weight of the completed prototype was 5.5 pounds, because when the device was modeled, the weight of the fiberglass, hardener, and paint were not taken into account. Since the device is greater than three pounds, it exceeded the goal weight and could adversely affect one's neck if it is worn for hours at a time. The first generation prototype incorporated 1.25" thick aluminum for the joint and .625" diameter tubing for the skeleton. Based on the stress analysis, it was inferred that the device was structurally overdesigned, which shows that the device was designed properly as the stress experienced within the aluminum of certain components, namely the joint blocks, were far below the tensile strength of the material. Although overdesigning the device would contribute to the safety of the driver, the inclusion of more material was translated to increasing the total weight of the device. Since the standard head and neck restraints currently on the market only weigh one to two pounds, the weight of this device would need to be reduced two or three pounds in order to be competitive with other devices and to allow a higher level of comfort for the user. A straightforward method of reducing the weight would be either to reduce the size of the joint blocks by using thinner aluminum stock, to reduce the size of the tubing used in certain areas of

the device where possible, or to utilize a lighter material overall that still has a relatively high strength. The less feasible method of reducing the weight would be to redesign the overall structure to minimize the use of metallic materials. The following sections outline the simple strategies that could be implemented to reduce the weight of the device along with their analyses that are to be considered for future development.

15.1.1. Pin Reduction

One of the options that could be implemented in the weight reduction process would be to incorporate steel pins of smaller diameters. If the diameter of the steel pin was reduced from .625” to .5”, or 12.7 mm, the resulting shear stress acting on the pin in a crash was determined through the following calculations:

$$\text{Shear Stress} = \frac{\text{Load}}{\text{Area}}$$

$$\text{Area} = \pi r^2 = \pi (6.35 \text{ mm})^2 = 126.6769 \text{ mm}^2$$

$$\text{Shear Stress} = \frac{16700 \text{ N}}{126.6769 \text{ mm}^2} \approx 131.8 \text{ MPa} \approx 19.1 \text{ ksi}$$

By reducing the size of the pin, the resulting shear stress increased from 12.2 ksi to 19.1 ksi. Even with the slight increase in the shear stress, the resultant stress was still under the tensile strength of the material; however, further reduction may result in high stress concentrations applied to the joint block due to the significant decrease in the cross-sectional area of the pin.

15.1.2. Optimization of the Female Block

Another possible alteration that could be made to the device to help lighten it would be to change the female side of the joint block, which can be done through various methods. First, the thickness of the block can be reduced to 1” rather than 1.25”, and the overall length can be shortened to 3.875” from the original 4”. Additionally, the holes made to receive the pins on the

wings can be changed from blind holes to through holes, which would reduce the amount of material used in both wings. The final alteration that could be done regarding the female joint block would be to implement small lightening holes and slots to remove excess material without affecting the integrity of the device. If these design changes were implemented into the design, the female blocks would be similar to the blocks shown in Figure 77.

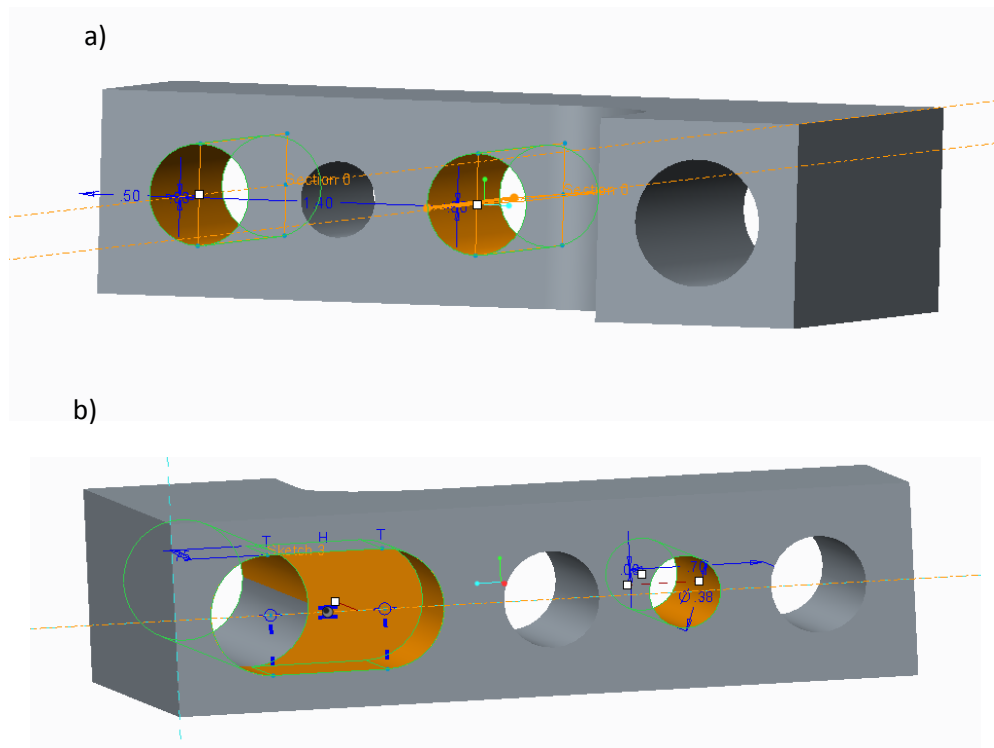


Figure 77. Female Block with (a) Through Holes, Lightning Holes, and (b) Slots

A stress analysis on the modified female block was performed. The contour plots revealed that the block still holds enough strength to prevent the von Mises stresses from exceeding their critical point so the device does not failure or experience permanent deformation. The plots for the von Mises and principal stresses are displayed in Figure 78 and Figure 79 respectively.

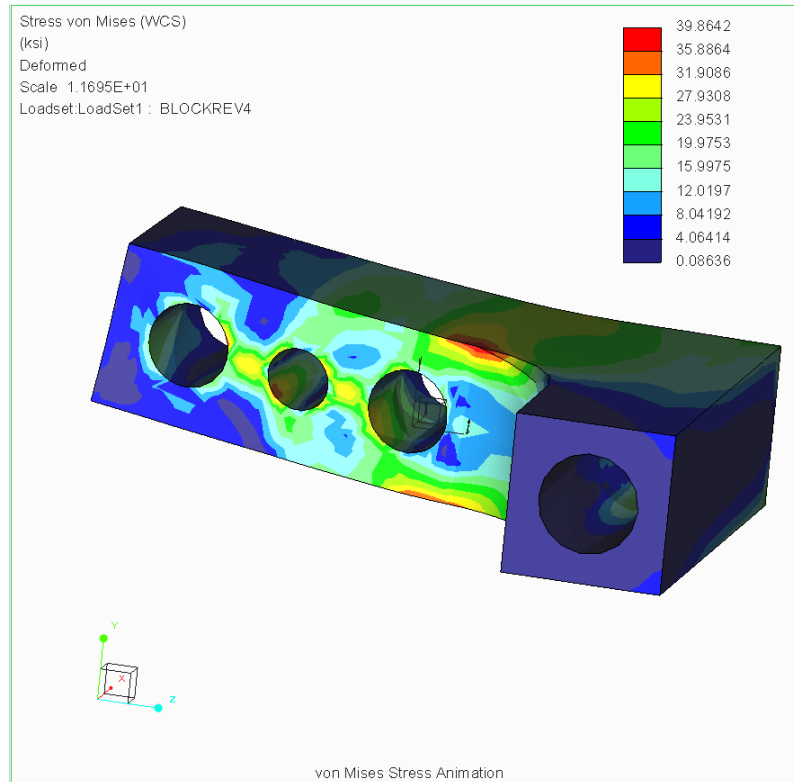


Figure 78. von Mises Plot of Female Block after the Alteration Under Full Frontal Loading

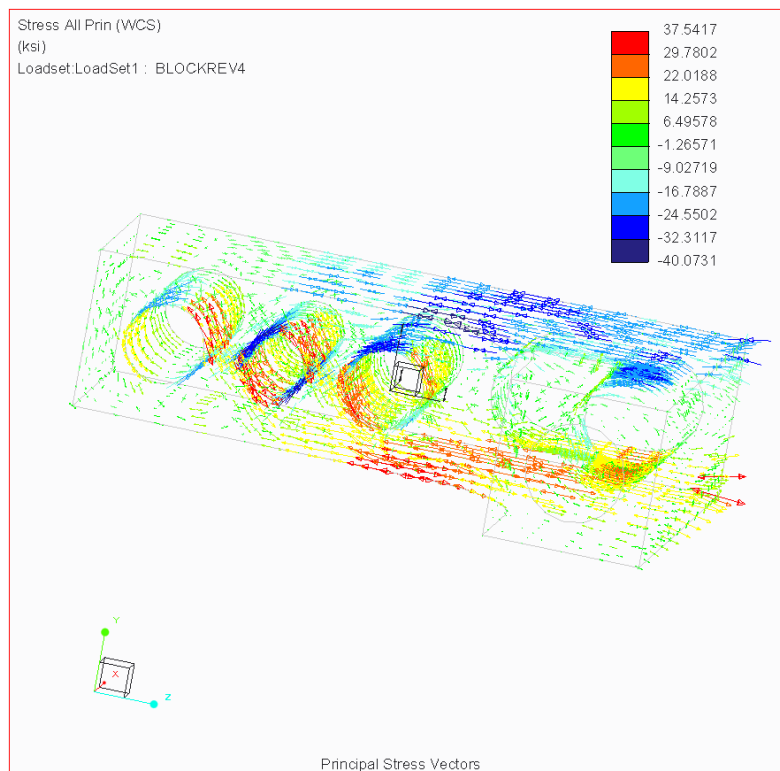


Figure 79. Plot of Principal Stresses on the Female block after the Alterations under Full Frontal Loading

The plot in Figure 78 shows that the maximum von Mises stress experienced in the female block was about 39.86 ksi, and the location of this stress is shown in red on the top region of the block near the hole for the steel pin. The plot of the principal stresses (Figure 79) demonstrates that the maximum principal stress was about 35.54 ksi, transpiring on the bottom of the block and within through holes. The portions of the joint shown in red in the figure are locations where the maximum principal stress occurred. Considering both plots showed that the maximum stresses were close to the yield strength of aluminum (40 ksi), this is as much reduction as this component can undergo without a full redesign, because pushing the stresses to far beyond the yeild strength could result permanent deformations, which will interfere with the release mechanics.

15.1.3. Optimization of the Male Block

The male block was reviewed and modified to reduce the weight of the device. First, the thickness was reduced from 1.25” to 1”. Next, the overall length reduced to 2.875” from 3” and lightening through holes were added to reduce unnecessary weight. The new version of the male block is depicted in Figure 80.

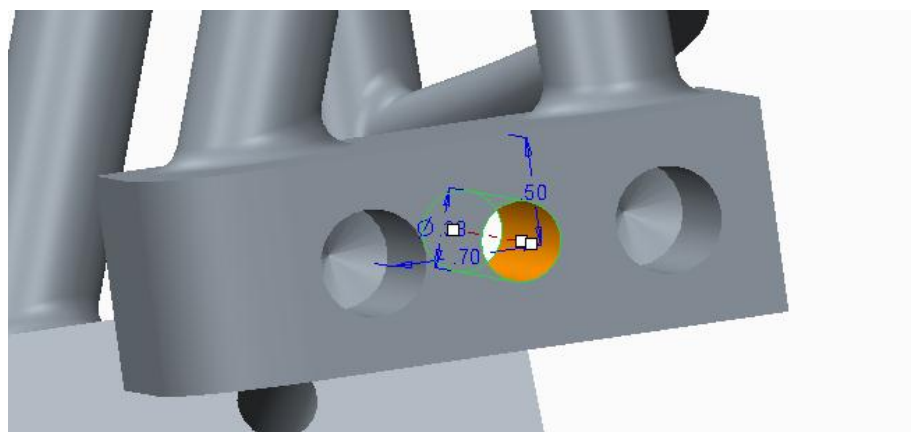


Figure 80. Alteration to the Male Block

The holes designated for the steel pins were not altered to be through holes in the male block, but kept them as blind holes as a means of affixing the pins to the device to limit movement of the pins when the device is in use.

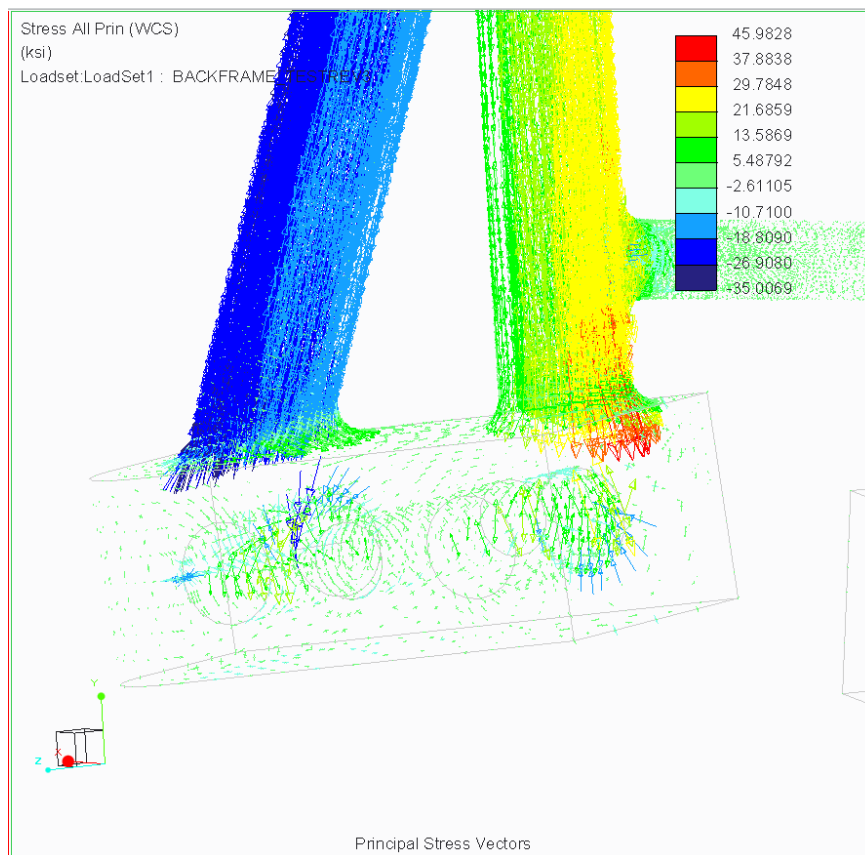


Figure 81. Plot of Principal Stresses on the Male Block after Alterations when under Full Frontal Loading

Utilizing the forces experienced in a crash involving an acceleration of 110G, a stress analysis was performed on the male block. Figure 81 shows the contour plot for the principal stresses that were experienced throughout the male block. The plot shows that the maximum stress around the holes is about 30 ksi, which does not exceed the yield strength of the material. As a result, there will not be any permanent deformation in the male block after the event of a crash, thus maintaining their original shape and functionality.

15.1.4. Optimization of the Back Frame

The back frame of the skeleton structure could undergo certain modifications to reduce the weight of the prototype. Through examination, it was determined that the outside diameter of the four support legs cannot be reduced; however, the inside diameter of the tubing can be changed so that the wall thickness is less than .1", or 3/32". The horizontal support rods diameter can also be reduced to .375" with wall thickness of 0.035". A stress analysis was performed on the back frame of the device using the forces in a 110G crash. Figure 82 shows the contour plot of the von Mises stresses on the back frame of the device from the stress analysis.

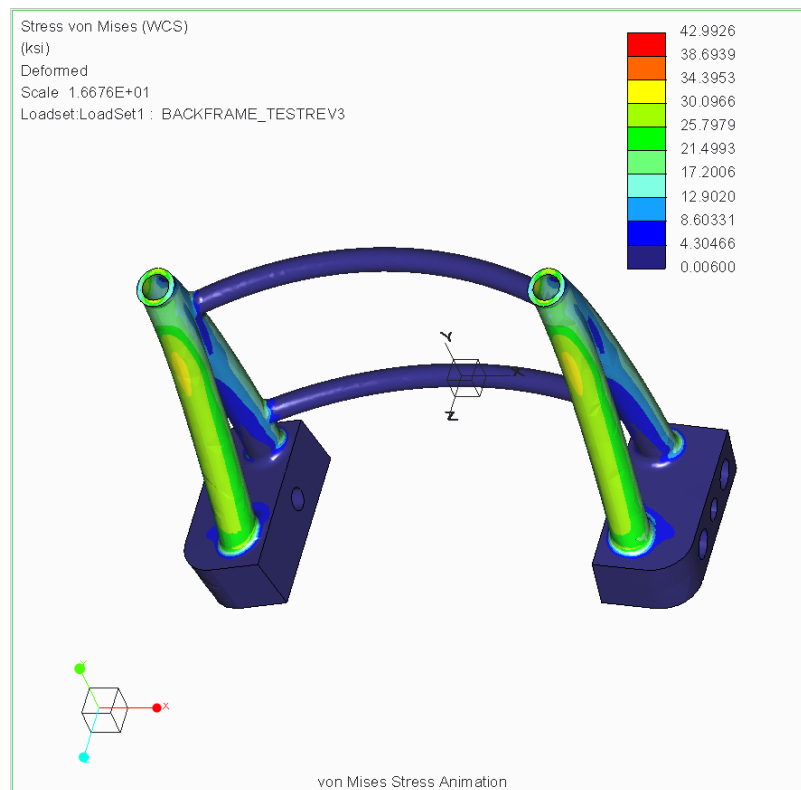


Figure 82. Plot of von Mises Stresses on the Back Piece after Alterations under Full Frontal Loading

The plot shows that the maximum von Mises stress was about 43 ksi, which is between the yield strength and the ultimate tensile strength of the material. As a result, it is likely that necking of the material might occur upon the application of forces greater than 8000 N, but the structure will not fracture, since all of the stresses were still below the ultimate tensile strength. Figure 83

shows the contour plot for the resulting principal stresses experienced upon the loading in a 110G crash.

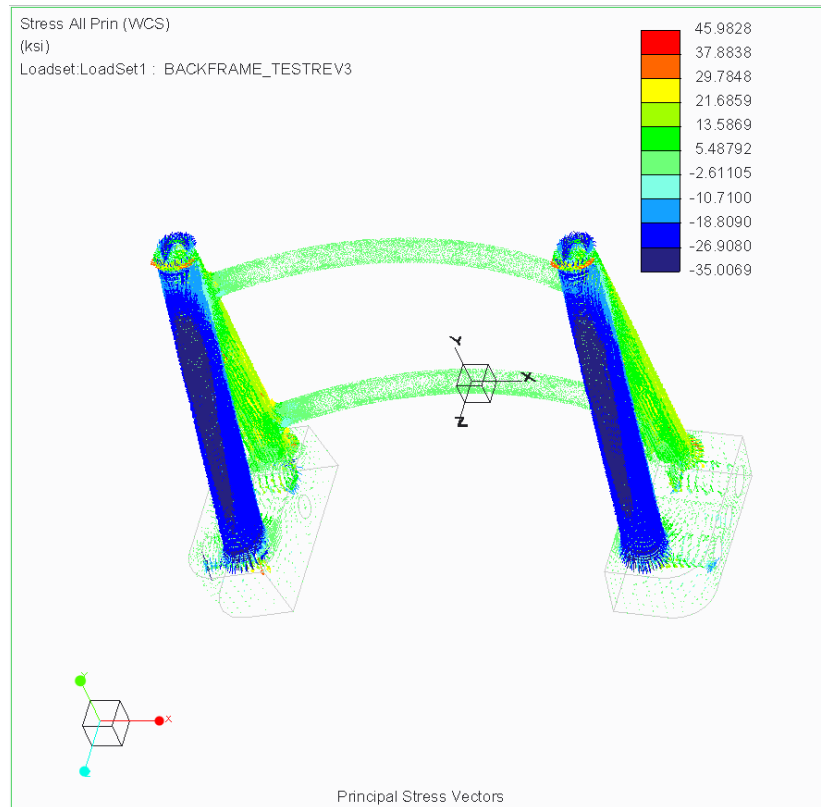


Figure 83. Plot of Principal Stresses of the Back Piece after Alterations under Full Frontal Loading

This plot demonstrates that the maximum principal stress was about 46 ksi, which occurred at the top to the back region where the force was applied. Although the maximum principal stress is greater than the ultimate tensile strength of the material, the von Mises stress is a better measure in terms of the accuracy in practice and experimentation to determine if failure will occur. However, the principal stresses in this case insinuate that the dimensions of the tubing should not be reduced any further. Considering the frame does not need to maintain its absolute shape to function properly, exceeding the yield strength should not pose any problems given the location

that these stresses occur. Figure 84 shows the plot regarding the displacement of the back region of the device when in a 110G crash.

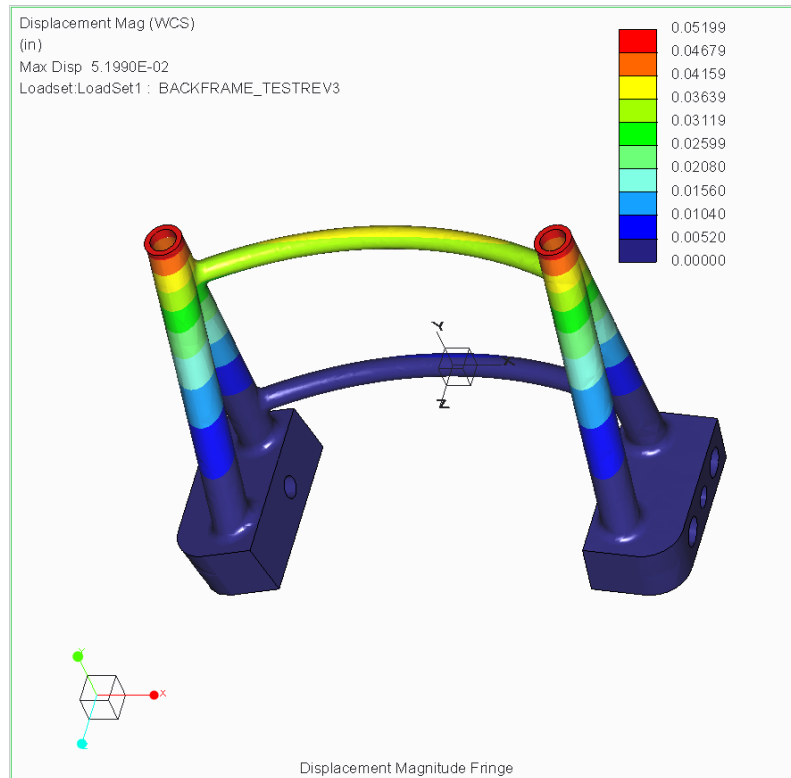


Figure 84. Displacement Plot of the Back Piece after Alterations when under Full Frontal Loading

The maximum deflection occurred at the top of the frame, where the force from the tethers is applied, and was about .05". Since the maximum displacement was small, the frame would still function as intended to restrain the forward and downward movement of the driver's head a crash even if it undergoes permanent deformation.

15.1.5. Alterations to the Wings

The last part of the device that needed to be optimized for weight was the wings. The aluminum tubing used to manufacture the wings can be reduced from .125" to slightly less than .1" (3/32") to match the alterations to the back frame. The overall length of each wing can be

reduced by 1”. Based on an analysis of the prototype, these structural changes are minor and should not affect the functionality of the wings, because the load applied from the harness will keep the wings from moving away from the driver’s body.

15.1.6. Overall Weight Reduction

Combining all the mentioned alterations, the new iteration of the prototype should have a total weight of 3.09 pounds, before applying the fiberglass, which shows that at least 1.64 pounds can be reduced from the existing design and remain functional. Upon the application of the fiberglass and hardener, the total weight of the device would be about 3.8 pounds, which is slightly over the recommended weight, but it would weigh almost two pounds less than the existing prototype. Further reduction of the weight of the device is possible, but advanced optimization strategies would be needed.

15.2. Latch Alterations

Based on the consultations with Jean Paul Cyr and Ray Dona, both suggested using an alternative to the style of latch featured on the prototype. The main problem with the window type latches was that they were positioned above the surface of the device and protruded into the safety belts, which could jeopardize the functionality and integrity of the safety harness. If the current latches were to be used in the future, a recess or cutout could be featured as previously mentioned. This would allow the latch to be mounted below the surface of the device, which would eliminate the problems associated with the protrusion of the latches into the safety harness during a competitive race. Since the user must move the belts from around the latch as currently designed, this would not inhibit the use of the latches. With the latch being mounted below the

surface, the safety harness is also less likely to become entangled with the latch, leaving the latch inoperable.

The other problem with problem with the prototype involved the method of releasing the wings from the yoke. Since the existing pins are parallel, the wings tend to jam and bind when attempting to remove the wing, because the tether attached to the wing is often pulled at an incorrect angle in relation to the wing, which inhibits the intended outward lateral motion when the latch is released. One way to prevent this from occurring would be to feature a single pin with a detent release as described in Chapter 14.1. This pin would be fixed to the outer wing; upon pulling the pin away from the body, the wing would easily be removed from the back region. Depictions of this type of joint are in Figure 72 and Figure 73 in Chapter 14.1. This would ultimately eliminate the need for an external latch mechanism.

15.3. Mold Alteration

When making the prototype of the final design, a male mold was generated, which entailed manufacturing the core structure and then wrapping fiberglass around the exterior surface of the mold. Due to the nature of a male-style mold, the outer surface finish of the fiberglass turned out to be rather poor, which did not make the exterior esthetically pleasing. Utilizing a female mold would improve the appearance of the device as it would feature a smoother surface finish and require less work. To produce a female mold, a 3-D model of the design would be needed prior to its formation. From the 3-D model, the profile of the outside surface of the device can easily be determined, and a mold can be created using the same geometry except as a “negative” treating the model as a “positive.” After the completion of the mold, fiberglass would be applied to the exterior portion of the mold. More details describing this method of generating a mold appear in Appendix F. Although this method would require more forethought and work

with CAD software, using a female mold would reduce the amount of work related to making the external layer to cover the core structure, and it would ensure the device would be manufactured as designed via the 3-D model.

15.4. Miscellaneous Alterations

As previously mentioned, another recommendation would be to use carbon fiber instead of fiberglass, as it is both stronger and lighter. Given the beneficial properties of carbon fiber, fewer layers would be required, which could slightly reduce the overall weight of the device. Another alteration, which could provide more comfort to the driver, would be to contour the wings, so the device involves a larger amount curvature from the part that is stationed on the shoulders to the top part of the wings. This curvature would be shaped similar to the upper torso of the user. Figure 85 shows a model of the device with wings involving a larger amount of curvature near the shoulder area. The red arrow in the figure shows the specific location where more curvature is needed in the wings to provide more comfort to the user.

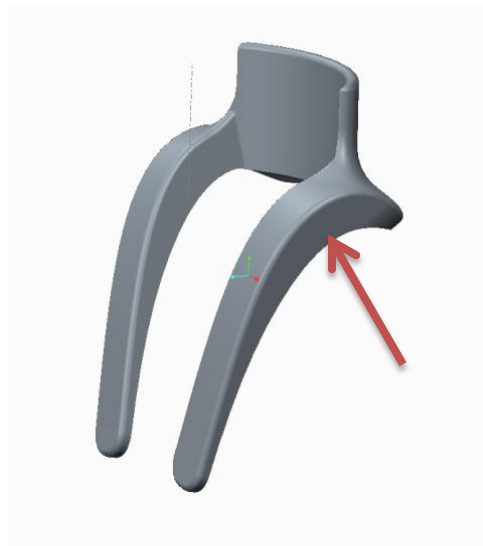


Figure 85. Device with Tapered Wings

This contouring would also permit the device to be secured to the upper torso better. Although foam was used to form the shape of the prototype, additional padding on the underside of the wings is needed to reduce the amount of pressure applied to the driver's shoulders and chest. The final alteration that would be advantageous in the future would be to have longer tethers attached to the wings or add a ball to the end of the tethers as a few individuals thought they were hard to find during the testing of the prototype. Lastly, the price point that resulted from the economic analysis would most probably not be the final selling price as the materials used to make the prototype would be bought in bulk, which would reduce the overall cost, and the quantity of material used per device could decrease to reduce the weight of the device.

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Appendix A - SFI Specification 38.1



SFI SPECIFICATION 38.1

EFFECTIVE: SEPTEMBER 23, 2011*

PRODUCT: Head and Neck Restraint Systems

1.0 GENERAL INFORMATION

- 1.1 This SFI Specification establishes uniform test procedures and minimum standards for evaluating and determining performance capabilities for Head and Neck Restraint Systems used by individuals engaged in competitive motorsports.
- 1.2 The procedures, test evaluations and standards contained herein, are intended only as minimum guidelines for construction and evaluation of products. Certification that products meet such minimum standards is made by the product manufacturer and products are not certified, endorsed or approved by SFI under this program.
- 1.3 Use of the "This Manufacturer Certifies That This Product Meets SFI Specification 38.1" logo/designation, the authorized artwork style, or conventional lettering by a manufacturer, on a subject product, is intended only to indicate that the manufacturer of the product has represented that they have submitted the product to the recommended tests, with positive results, in compliance with the standards established herein.
- 1.4 This SFI Specification requires a demonstration that the product of a manufacturer meets or exceeds the requirements when the manufacturer enters the program, and on a periodic basis thereafter. Any manufacturer may participate in the program by providing Head and Neck Restraint Systems that meet or exceed the SFI Specification 38.1 test standards, by complying with the requirements of the SFI Specification 38.1 program, and by signing a licensing agreement with the SFI Foundation, Inc.

- 1.5 Compliance with this specification is entirely voluntary. However, when a manufacturer provides Head and Neck Restraint Systems in compliance with all requirements of the SFI Specification 38.1 and enters into the licensing agreement with the SFI Foundation, Inc., they may certify that compliance with such standards is in accordance with the guidelines established herein.
- 1.6 Manufacturers wishing to participate in the program, in addition to the other requirements of this specification, must label each of their products with the manufacturer's name, trademark or symbol as well as the model number, part number and the date of manufacture of the product.
- 1.7 No manufacturer may display the SFI logo/designation on their product unless the manufacturer has signed a licensing agreement with SFI and has successfully complied with all the requirements of this specification and the self-certification program.

2.0 DEFINITIONS

- 2.1 Head and Neck Restraint: An active Head and Neck Restraint System is a protection ensemble providing an alternative load path which decreases both neck stress and head excursion during a vehicle impact without reliance on helmet impact into structures or nets.
- 2.2 Separate Restraining Devices:
 - A. Linkages attached to the helmet which transfer restraining loads directly to the helmet from the main device which is secured to the driver's shoulders, torso, etc. Methods for attachment of these linkages to the helmet and main device shall be prescribed by the manufacturer.
 - B. The main device shall be a mechanism held tightly to the driver's torso by seat belts or other strap systems such that the reactive load carrying components move directly with the torso and controls head, neck, and torso relative positions during forward or off-center impact situations.
- 2.3 Reaction Linkage: The means by which the head force necessary to limit displacement of the head with respect to the torso is reacted. Acceptable reaction linkages could include load paths to the torso or to the restraint webbing. Direct attachment to react loads to a fixed point or points on a vehicle structure or restraint webbing will not be acceptable because of the potential for torso displacements with respect to these points. Imposed loading by the reaction linkage to other areas of the body should be applied using approaches demonstrated to be practical without imposing risk of serious injury.

- 2.4 The Head and Neck Restraint System must be designed and manufactured to allow freedom of movement of head, torso, arms, etc., commensurate with operating a race vehicle under all race and associated conditions.
- 2.5 Adjustment and release mechanism(s) shall be accessible to both the user and to external personnel such that no additional motion is required, other than the release of the seat belts, to disengage the Head and Neck Restraint System during emergency situations.
- 2.6 All or any portion of the Head and Neck Restraint System pertaining to this specification shall remain as constructed by the original manufacturer and not modified.
- 2.7 Effective January 1, 2012, Head and Neck Restraint Systems shall be inspected for recertification every five years after the date of original certification. Product inspection, maintenance, and/or replacement procedure is per individual manufacturer. Inspection must be done by the original manufacturer only, and not their authorized resellers or dealers. When a unit is determined by the manufacturer to be acceptable for continued service and in compliance with the current version of the specification, the original manufacturer shall place on the product a new SFI 38.1 conformance label marked with the inspection date.

3.0 CONSTRUCTION

3.1 MATERIALS

The materials used in the construction of the Head and Neck Restraint System shall be resistant to the elements to which they are exposed in normal service. Besides environmental considerations such as heat and UV light, these elements include fluids used in and around motor vehicles that may come in contact with the restraint system. All metal rivets, bolts, buckles, adjusters, etc. shall be corrosion resistant and have sharp edges and burrs removed. The materials and design shall not promote combustion as defined by flame resistance testing herein.

4.0 MODEL CLASSIFICATION

Any variation of the original design, i.e. construction methods, materials, size and quantity of straps or links shall be considered a model change. Any change which affects the kinematic response of the user of the device, must be tested at the judgment of SFI. SFI will assemble a review panel through which manufacturers can present items of modification that they feel do not constitute additional testing.

5.0 TESTING

5.1 IMPACT PERFORMANCE

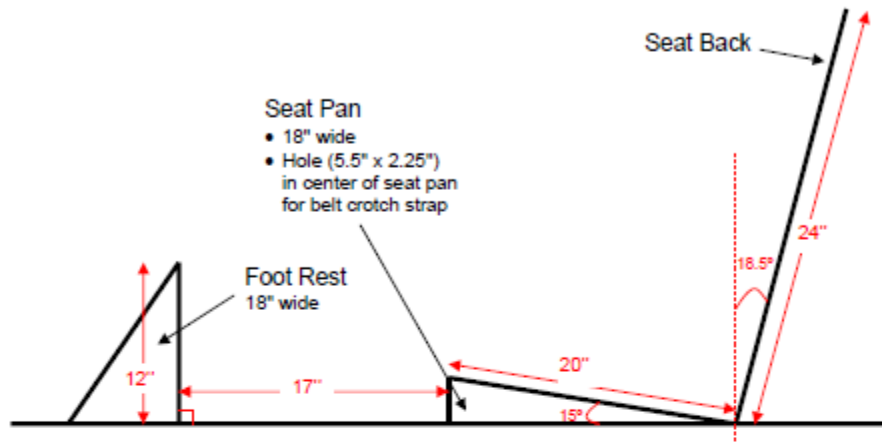
5.1.1 SAMPLES

Test samples shall be fully processed new Head and Neck Restraint Systems that are representative of devices currently being produced or to be produced. All necessary attachment and adjustment hardware along with instructions shall be supplied by the certifying manufacturer.

5.1.2 APPARATUS

- A. The system shall be tested using a 50th percentile male Hybrid III anthropomorphic test device (ATD) seated and restrained in a pan type seat assembly per Figure 1 and with a Nylon SFI Specification 16.1 six-point driver restraint system (to be supplied by SFI) mounted to a conventional race car style mounting frame without steering wheel and steering column. The driver restraint system shall be installed so that each shoulder belt is horizontal from the top of the Head and Neck Restraint Device system to the belt attachment point. The attachment points for the lap belts and anti-submarine belt (crotch strap) may not be altered in any way. Head side supports and supplemental head nets for the seat shall not be included. A full-face racing helmet weighing 3.0 lbs. (1.36 kg) minimum without face shield shall be fitted to the Hybrid III ATD to achieve a typical fit per the helmet manufacturer's instructions. If attachment of tethers or other devices to the helmet are required, drilling and attachment location, methods and hardware shall be per manufacturer's instructions.

Figure 1
Test Sled Seat Assembly



- B. Instrumentation in the Hybrid III ATD will be set up to read Upper Neck Tension and Compression Forces, and all data acquisitions necessary for calculating N_{ij} (per FMVSS 208.) The data from the upper neck transducers will be collected and filtered at SAE J211/1 Rev. March 95 channel frequency Class 600.
- C. A test sled (hydraulic or other) shall be capable of propelling the entire assembly in paragraph 5.1.2.A above in a manner to achieve a pulse contour per Figures 2A and 2B, producing a nominal 68G peak, 63 KPH (39.1 mph) velocity change.

Figure 2A

NASCAR Pulse
Velocity

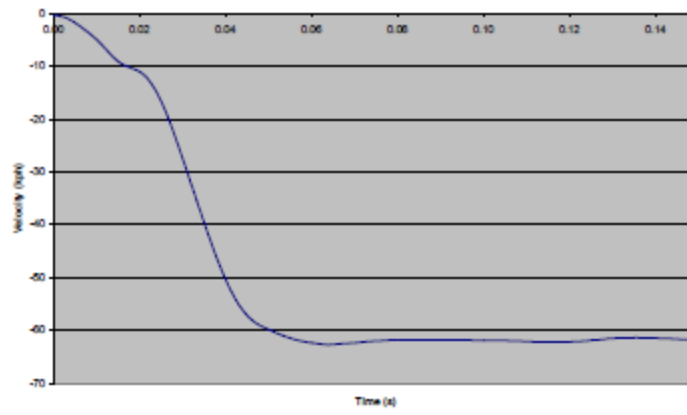
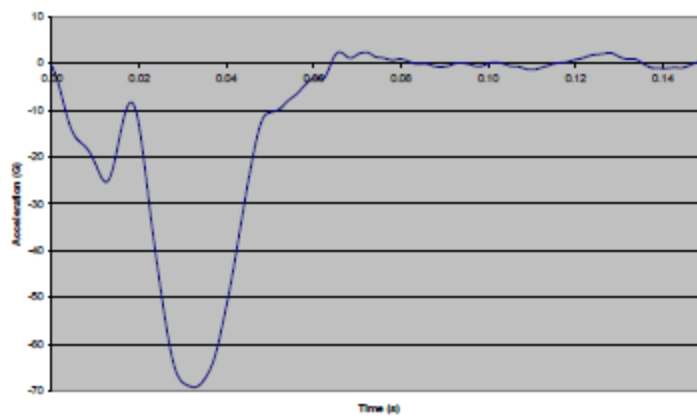


Figure 2B

NASCAR Pulse
Acceleration



- D. If it becomes desirable to utilize an alternative lab rather than MGA Research Lab or to employ a different ATD than the Hybrid III, then test procedures and requirements may need to be reevaluated at the discretion of SFI.

5.1.3 PROCEDURE

- A. The Head and Neck Restraint System shall be assembled per the manufacturer's instructions to the 50th percentile male Hybrid III test device (ATD) and the ATD then shall be seated and restrained in the seat and mounting frame with the full face helmet fitted, all as described in paragraph 5.1.2.A of this specification. This complete assembly shall be mounted on the test sled.
- B. The test sled shall be propelled to produce the racing acceleration pulse (Figures 2A and 2B) at a nominal 68G peak, 63 KPH (39.1 mph) velocity change. For initial design validation, two (2) frontal tests and one (1) 30° right frontal test will be required. The results of both frontal tests and the 30° right frontal test must meet the requirements of paragraph 6.1.1. For periodic revalidation, one (1) frontal test and one (1) 30° right frontal test will be required. The results of the frontal test and the 30° right frontal test must meet the requirements of paragraph 6.1.1.
- C. The data recorded in the test shall be analyzed for the first 80 milliseconds of the test and then analyzed at 120 milliseconds of the test.

5.2 HEAD AND NECK RESTRAINT DEVICE SURFACE FLAME RESISTANCE

The test shall be conducted at an ambient temperature between 10°C (50°F) and 30°C (86°F).

5.2.1 SAMPLES

One Head and Neck Restraint System sample at ambient temperature shall be tested.

5.2.2 APPARATUS

A. THERMAL LOAD

The thermal load shall be applied by a gas Bunsen burner, with an inside diameter of 0.4 inch (9.5mm).

B. TIMING DEVICE

A timing device with an accuracy of ± 0.5 seconds shall be used to measure combustion rates.

C. FIXTURE

A fixture shall be used to support the Head and Neck Restraint System sample.

5.2.3 PROCEDURE

The Bunsen burner flame height shall be adjusted to 1.5 inches (38mm) and positioned perpendicular to the head and neck restraint device surface in at a site chosen by the test laboratory. The device surface shall be subjected to the thermal load at a distance of 0.75 inch (19mm) from the surface of the component to the center of Bunsen burner nozzle for a period of 15 ± 1 seconds and immediately removed. Measurement of the after-flame time shall start simultaneously with the removal of the flame. The after-flame time is the time the sample continues to flame after the burner flame is shut off.

5.3 TETHER FLAME RESISTANCE

The test shall be conducted at an ambient temperature between 10°C (50°F) and 30°C (86°F).

5.3.1 SAMPLES

One Head and Neck Restraint tether sample at ambient temperature shall be tested.

5.3.2 APPARATUS

A. THERMAL LOAD

The thermal load shall be applied by a gas Bunsen burner, with an inside diameter of 0.4 inch (9.5mm).

B. TIMING DEVICE

A timing device with an accuracy of ± 0.5 seconds shall be used to measure combustion rates.

C. FIXTURE

The test must be conducted in a draft free horizontal cabinet in accordance with Federal Test Method Standard 191 Model 5906 or equivalent.

5.3.3 PROCEDURE

The tether sample shall be mounted horizontally in the test cabinet. The Bunsen burner flame height shall be adjusted to 1.5 inches (38mm) and located in the test cabinet so that the Bunsen burner nozzle is positioned below one end of the tether sample as shown in Figure 3. The tether shall be subjected to the thermal load at a distance of 0.75 inch (19mm) from center of Bunsen burner nozzle to the center of the bottom edge of the tether for a period of 15 ± 1 seconds and immediately removed. Measurement of the speed of combustion shall start simultaneously with the removal of the flame.

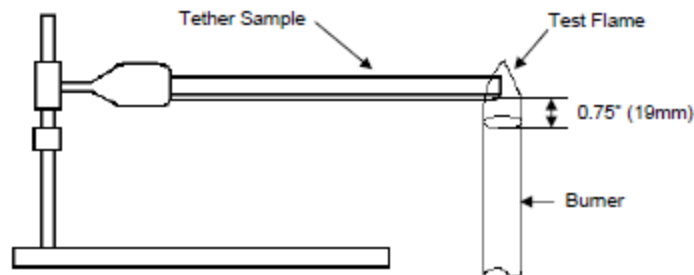


Figure 3
Test Flame Fixture Inside Test Cabinet

6.0 PROOF OF COMPLIANCE

Head and Neck Restraint System certifying manufacturers are required to provide the following information to enroll in this program:

6.1 TEST RESULTS

Test results shall be documented in a test report.

6.1.1 IMPACT PERFORMANCE FOR EACH TEST (procured from Hybrid III test device).

0 to 80 milliseconds:

Maximum Upper Neck Tension	2,500N (562 lbs)
Maximum Upper Neck Compression	2,500N (562 lbs)
Maximum Value of NIJ	1.0

80 to 120 milliseconds:

Maximum Upper Neck Tension	3,200N (719 lbs)
Maximum Upper Neck Compression	3,200N (719 lbs)
Maximum Value of NIJ	1.0

6.1.2 HEAD AND NECK RESTRAINT DEVICE SURFACE FLAME RESISTANCE

When the surface is tested per paragraph 5.2.3, the after-flame time, or time to self-extinguish, shall be within 10 seconds.

6.1.3 TETHER FLAME RESISTANCE

The speed of combustion of the tether per paragraph 5.3.3 shall be less than or equal to 3 inches/minute (77mm/minute).

Appendix B – Determining the Forces and Moments using 68G

$$\text{Acceleration} = 68 \text{ g's} = 68 \text{ g's} * 9.8 \frac{\text{m}}{\text{s}^2} = 666.4 \frac{\text{m}}{\text{s}^2} \approx 670 \frac{\text{m}}{\text{s}^2}$$

Anthropometric Data for 50th percentile male (Anthropometry and Biomechanics)

$$m_{\text{head}} = 4.4 \text{ kg}$$

$$m_{\text{neck}} = 1.1 \text{ kg}$$

$$m_{\text{top torso}} = 26.11 \text{ kg}$$

$$m_{\text{bottom torso}} = 2.5 \text{ kg}$$

$$\text{distance from bottom of neck to center of mass of the head} = .142 \text{ m}$$

$$\text{distance from the bottom of the torso to center of mass of the torso} = .476 \text{ m}$$

$$m_{\text{helmet}} = 2.4 \text{ kg}$$

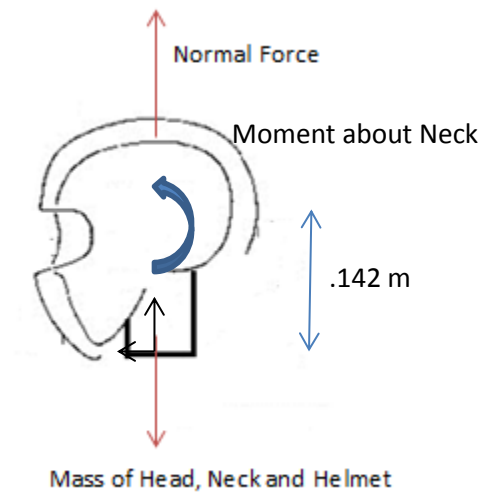


Figure 86. Free Body Diagram of Head and Neck

Neck, Helmet, and Head

The following calculations show the force that the head and neck of the driver applies to the device in the event of a crash with an acceleration equivalent to 68G. The moment in regards to the head and neck was also calculated using the base of the neck as the point about which the lever arm rotates.

$$\text{total mass} = m_{\text{head}} + m_{\text{neck}} + m_{\text{helmet}} = 4.4 \text{ kg} + 1.1 \text{ kg} + 2.4 \text{ kg}$$

$$\text{total mass} = 7.9 \text{ kg}$$

$$F_h = ma = (7.9 \text{ kg}) \left(670 \frac{\text{m}}{\text{s}^2} \right) \approx 5300 \text{ N} \approx \mathbf{1200 \text{ lb}}$$

$$M_h = Fr = (5300 \text{ N})(.142 \text{ m}) \approx 750 \text{ Nm}$$

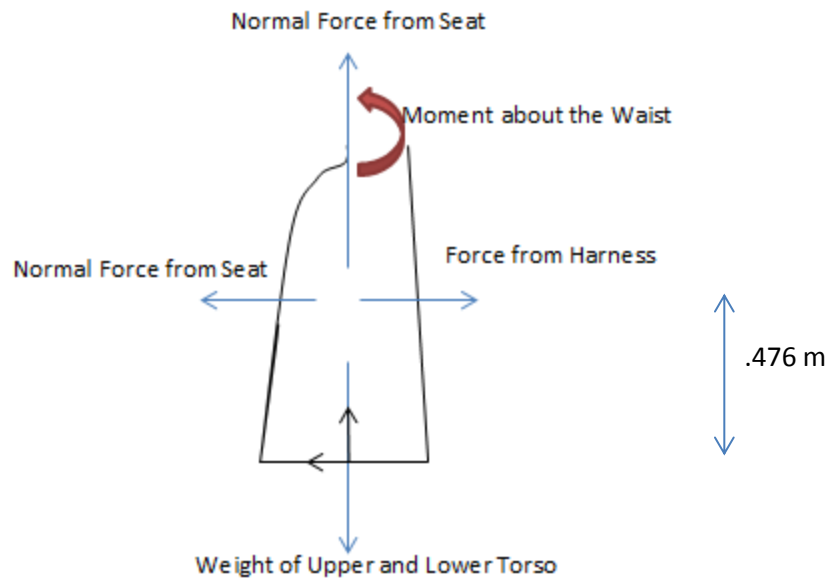


Figure 87. Free Body Diagram of the Torso

Torso

The following calculations show the force that the torso of the driver applies to the harness when in a 68G crash. The moment was also calculated using the waist of the driver as the point at which the lever arm rotates.

$$total\ mass = m_{top\ torso} + m_{bottom\ torso} = 26.11\ kg + 2.5\ kg = 28.61\ kg$$

$$F_{torso} = ma = (28.61\ kg) \left(670 \frac{m}{s^2} \right) \approx 19000\ N \approx \mathbf{4300\ lb}$$

$$M_{torso} = Fr = (19000)(.476\ m) \approx 9050\ Nm$$

Appendix C – Determining the Forces and Moments using 110G

$$\text{Acceleration} = 110 \text{ g's} = 110 \text{ g's} * 9.8 \frac{\text{m}}{\text{s}^2} = 1078 \frac{\text{m}}{\text{s}^2} \approx 1080 \frac{\text{m}}{\text{s}^2}$$

Anthropometric Data for 50th percentile male (Anthropometry and Biomechanics)

$$m_{\text{head}} = 4.4 \text{ kg}$$

$$m_{\text{neck}} = 1.1 \text{ kg}$$

$$m_{\text{top torso}} = 26.11 \text{ kg}$$

$$m_{\text{bottom torso}} = 2.5 \text{ kg}$$

$$\text{distance from bottom of neck to center of mass of the head} = .142 \text{ m}$$

$$\text{distance from the bottom of the torso to center of mass of the torso} = .476 \text{ m}$$

$$m_{\text{helmet}} = 2.4 \text{ kg}$$

Neck, Helmet, and Head

The following calculations show the force that the head and neck of the driver applies to the device in the event of a crash with an acceleration equivalent to 110G. The moment in regards to the head and neck was also calculated using the base of the neck as the point about which the lever arm rotates.

$$\text{total mass} = m_{\text{head}} + m_{\text{neck}} + m_{\text{helmet}} = 4.4 \text{ kg} + 1.1 \text{ kg} + 2.4 \text{ kg}$$

$$\text{total mass} = 7.9 \text{ kg}$$

$$F_h = ma = (7.9 \text{ kg}) \left(1080 \frac{\text{m}}{\text{s}^2} \right) \approx 8500 \text{ N} \approx 1900 \text{ lbf}$$

$$M_h = Fr = (8500 \text{ N})(.142 \text{ m}) \approx 1200 \text{ Nm}$$

Torso

The following calculations show the force that the torso of the driver applies to the harness when in a 110G crash. The moment was also calculated using the waist of the driver as the point at which the lever arm rotates.

$$\text{total mass} = m_{\text{top torso}} + m_{\text{bottom torso}} = 26.11 \text{ kg} + 2.5 \text{ kg} = 28.61 \text{ kg}$$

$$F_{\text{torso}} = ma = (28.61 \text{ kg}) \left(1080 \frac{\text{m}}{\text{s}^2} \right) \approx 30900 \text{ N} \approx 6950 \text{ lb}$$

$$M_{\text{torso}} = Fr = (30800)(.476 \text{ m}) \approx 14700 \text{ Nm}$$

Appendix D – Preliminary Engineering Drawings of Parts and Assembly of Skeleton

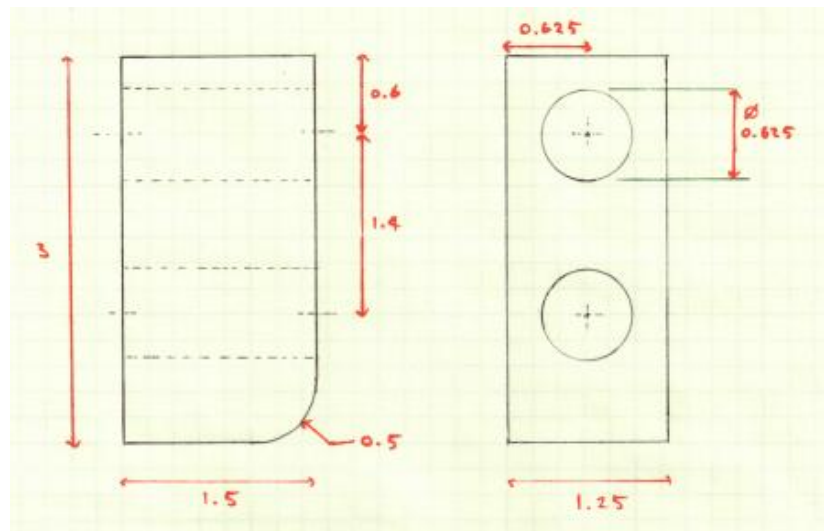


Figure 88. Basic Drawing of Male Block of the Joint

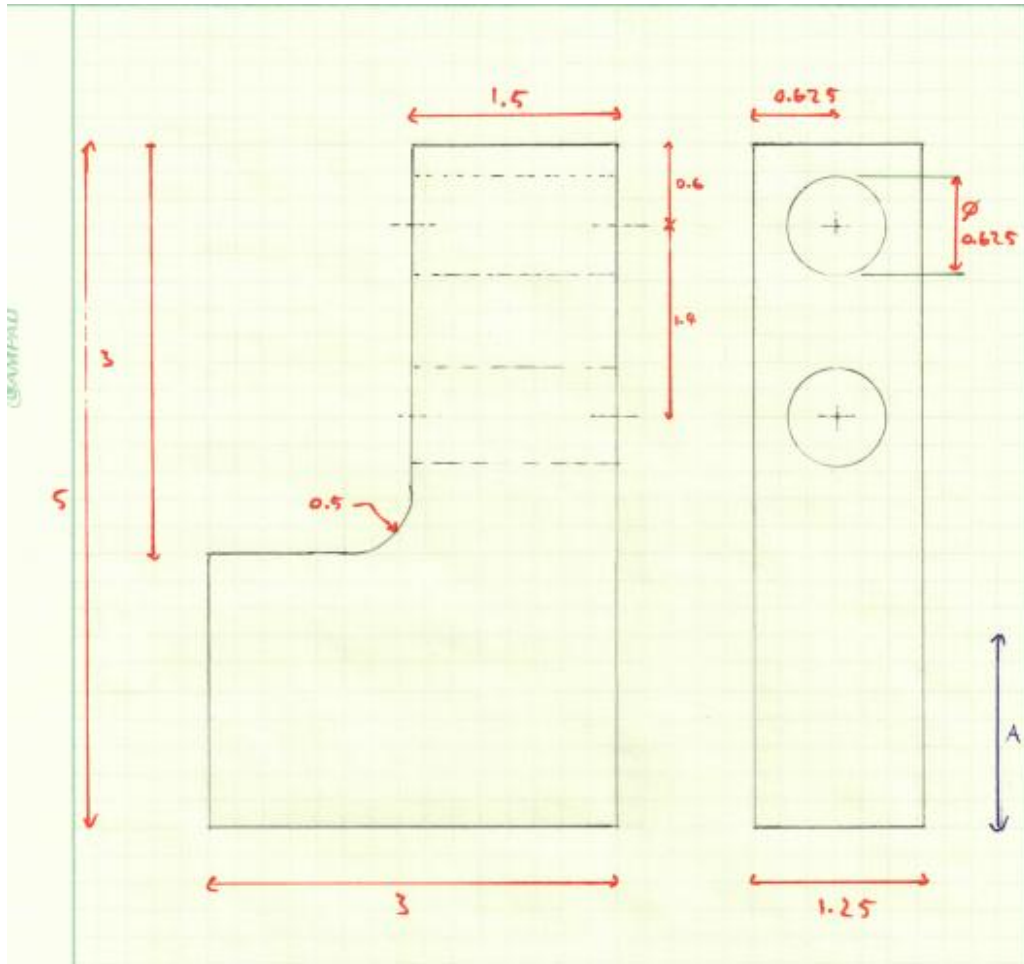


Figure 89. Basic Drawing of Female Block of Joint

All of the dimensions in these figures are in inches.

Appendix E – Creo Engineering Drawings of Parts and Assembly of Skeleton

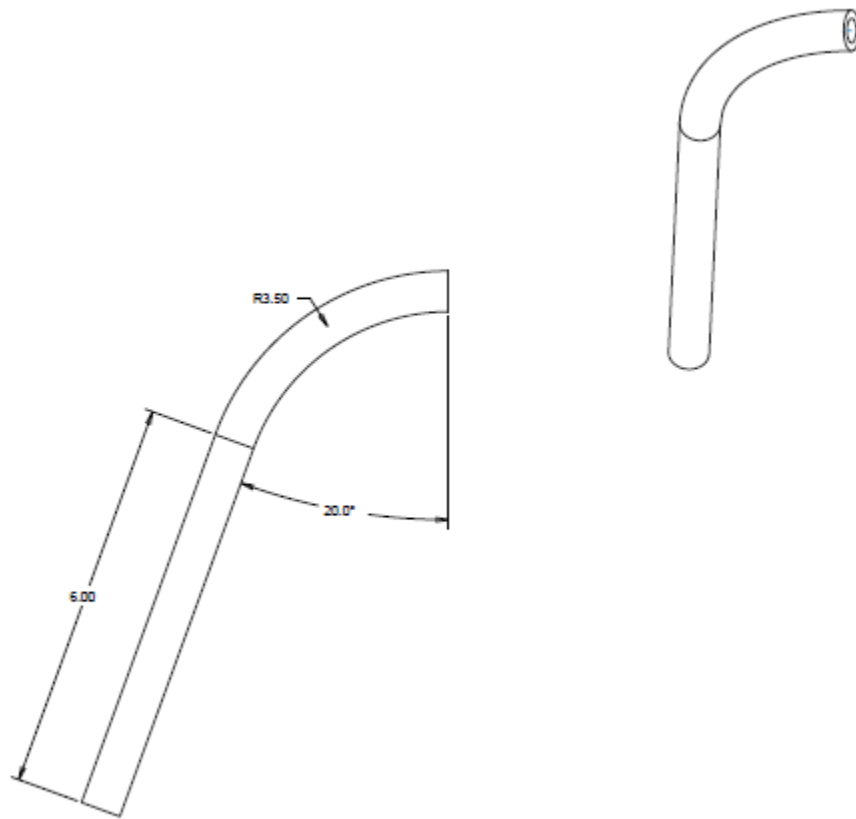


Figure 90. Drawing of the Wing Portion of the Skeleton

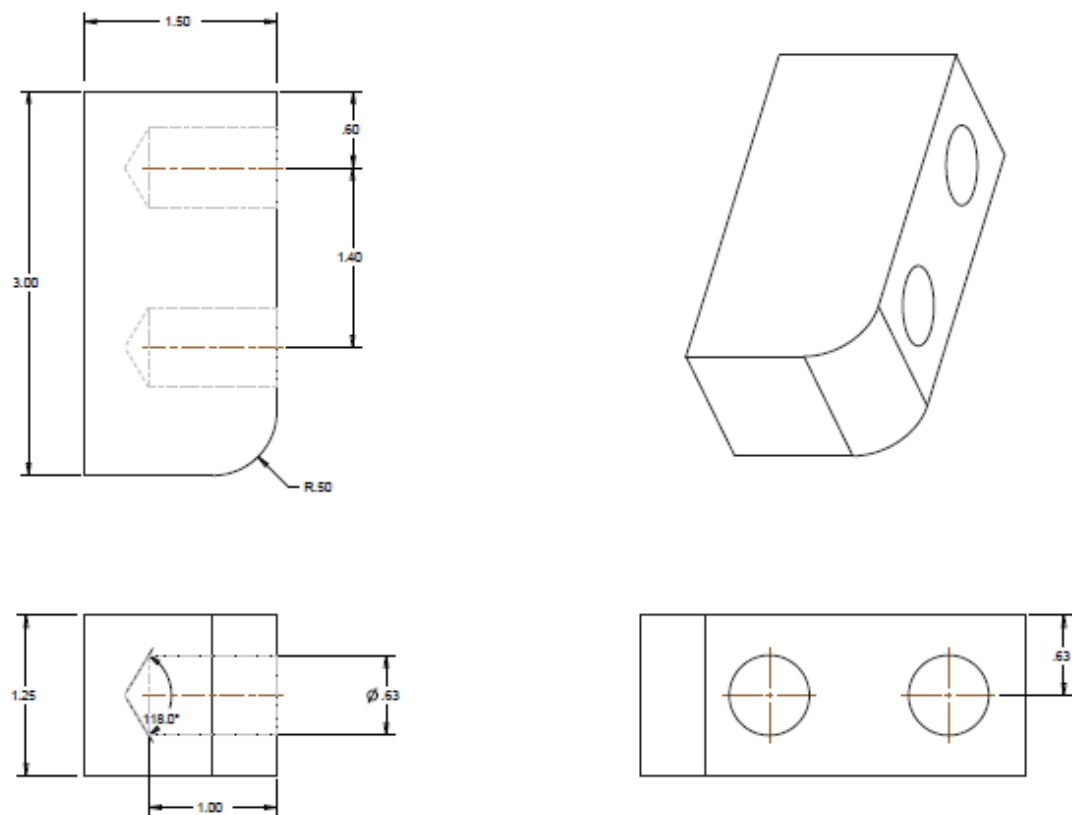


Figure 91. Drawing of the Male Block of Joint in Different Views

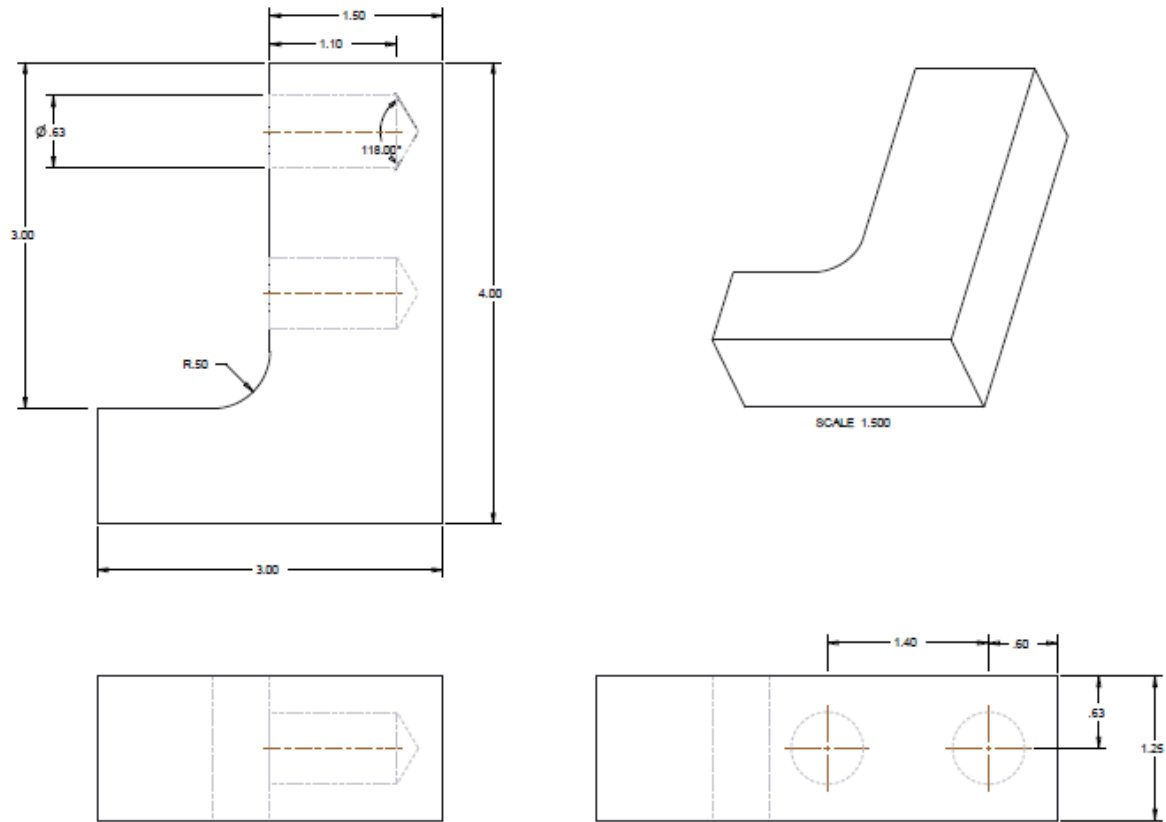


Figure 92. Drawing of Female Block of Joint in Different Views

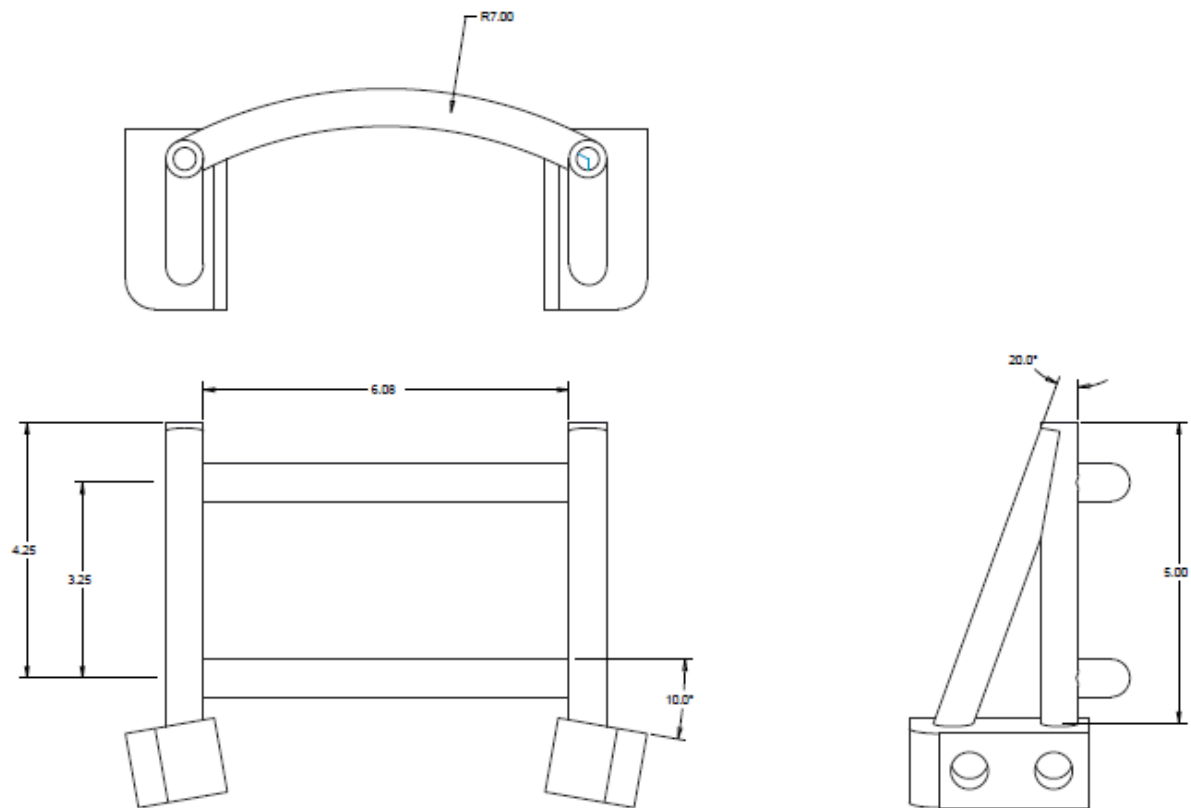


Figure 93. Drawing of Back Frame of Device

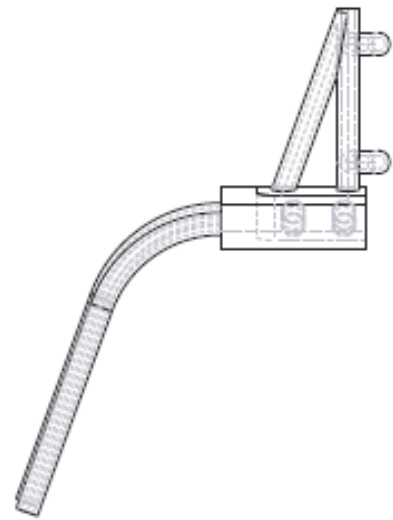
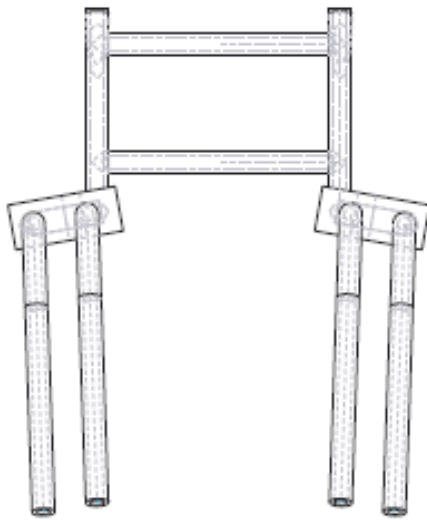
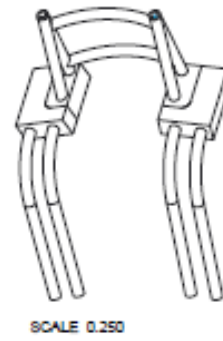
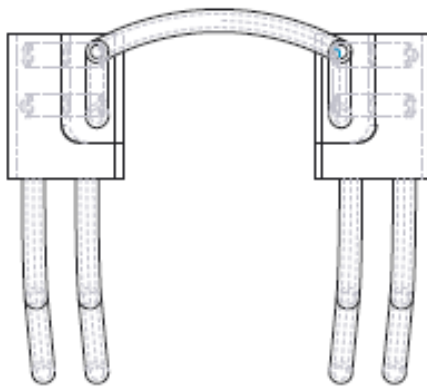


Figure 94. Drawing of the Complete Skeleton of the Device

Appendix F – Generating Molds for Manufacturing

When constructing a product made of either carbon fiber or fiberglass, the first step to construct a mold. There are two main types of molds that can be constructed: a female mold, which is a part formed on an inside surface and male mold, which is a part formed on the outside surface. The following description shows how to create a male mold, while the device proposed in this project may require female style molds and male alike. The benefit to a female mold is the exterior surface of the product yielded, since formed inside of the mold, results in having a smoother, finished surface, whereas a male mold had the “finished” side facing in. The process of making a female mold is similar to that of making a male mold, however slightly different processes could be required.

One of the simplest ways to construct a mold is by using styrofoam. Either a large, appropriately sized piece can be bought or several layers can be stacked and glued together shown in Figure 95.



Figure 95. Layers of Styrofoam for Molding

Once the material is of the correct size, the process of shaping the mold can begin. Initially, the material needs to be cut to a rough shape. This can be done by using different pieces of equipment, such as a bandsaw, hack or coping saw, or a heated wire specifically for cutting styrofoam. The rough shape can easily be generated by printing a multi-view drawing from a CAD model (1:1 size) and positioning it on the styrofoam. Once the mold is cut to a general shape, sand paper, a cheese grater, or a rasp can be used to start shaping the radii needed, which is depicted in Figure 96.



Figure 96. Shaping the Radii of the Mold

Before applying the sheet to the surface of the mold, a form of a mold release will need to be applied. Several materials can be used as a mold release, such as car wax to a specific form of commercially available mold release. If Styrofoam is used to generate the mold, it is best to cover the surface of the Styrofoam with painter's tape, which is shown in Figure 97.



Figure 97. Painters Tape is applied to the Styrofoam before car wax applied to both the sheet metal and tape as mold releases

Next, the sheet of fiberglass or carbon fiber can be cut out to fit the mold. The material is then smoothed to remove any wrinkles so the edges of the mold can be covered as well, which is depicted in Figure 98. If carbon fiber is being used, the sheet can be cut by with standard scissors; however, specialized sheets are necessary if that were the case.

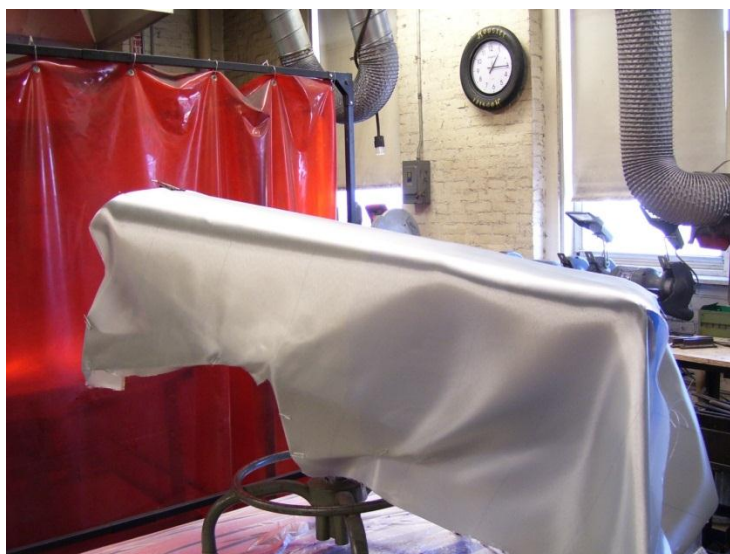


Figure 98. Applying Carbon Fiber to Mold

Once the raw sheet is positioned and smoothed to the desired shape, the epoxy resin can then be mixed and applied. This is done using the directions as listed on the container. This resin will dry and harden quickly in the container, so application of resin must be done immediately to ensure proper adhesion. Also, it is best not to apply an excess amount of resin as it affects the aesthetics, which require additional sanding to its removal. Two to three coats of resin are normally applied for coating, and depending on the strength, one to three layers of fiberglass or carbon fiber are necessary. Finally, after the final coats of resin have been applied and dried, the hardened material can be cut to its final shape and separated from the mold. If necessary, fillers such as Bondo can be applied and sanded to improve the final appearance.

Appendix G – Instruction Manual for Prototype

This device is to be used in conjunction with four-, five-, six-, or seven-point racing harnesses featuring three-inch wide belts. The device should also be equipped with quick release helmet anchors. These can be purchased at a cost from HANS/Simpson Racing or other safety equipment suppliers.

INSTALLATION:

The device must be placed over the driver's shoulders. This can be done before or after entering the car. Once in the seated position, the shoulder belts must be secured across the wings, which is depicted in Figure 99.

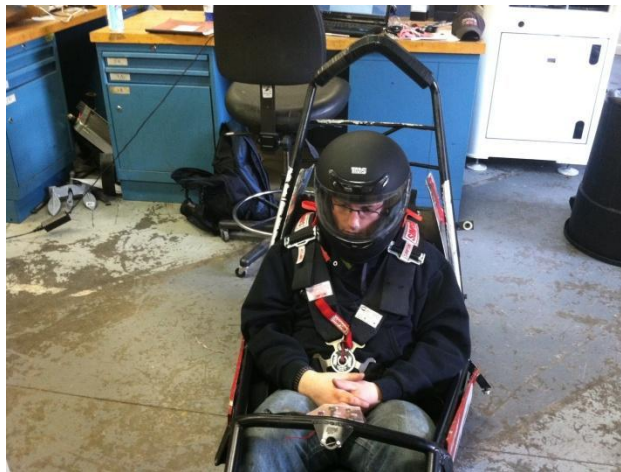


Figure 99. User Secured in the Mock Cockpit with Shoulder Belts over the Wings of the Device

To ensure the tethers used to remove the wings of the device remain in the same place, Velcro strips were applied to the wings so the driver can find the tethers quickly in an emergency. The helmet can then be worn by the user and the quick releases on the helmet can be secured. Similar to the tethers for the wings, the tethers for the quick releases are seen fastened to the helmet's sides using Velcro (Figure 100).



Figure 100. User Wearing the Helmet with Quick Release Tethers Attached to the Helmet

The helmet can then be worn by the user and the quick releases on the helmet can be secured. Similar to the tethers for the wings, the tethers for the quick releases are seen fastened to the helmet's sides using Velcro (Figure 100).

EXITING THE VEHICLE:

These steps must be followed in order to ensure the driver successfully exits the car in case of a fire or other emergency.

Step 1: Pull the quick release (Figure 101 and Figure 102) on the harness.

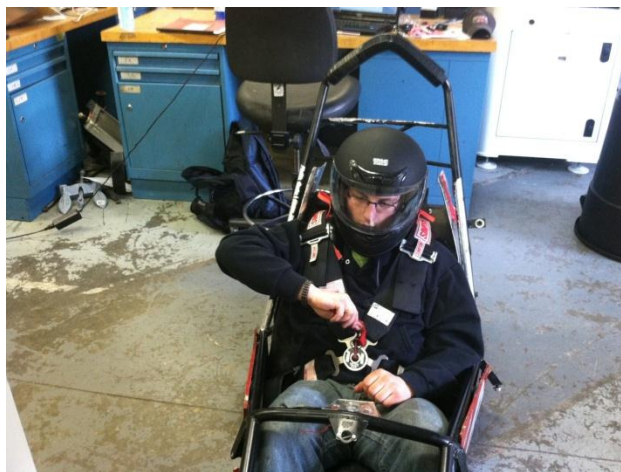


Figure 101. User Pulling the Quick Release on the Harness



Figure 102. User with the Belts of the Harness Released

Step 2: Move belts out of the way as necessary (Figure 103).

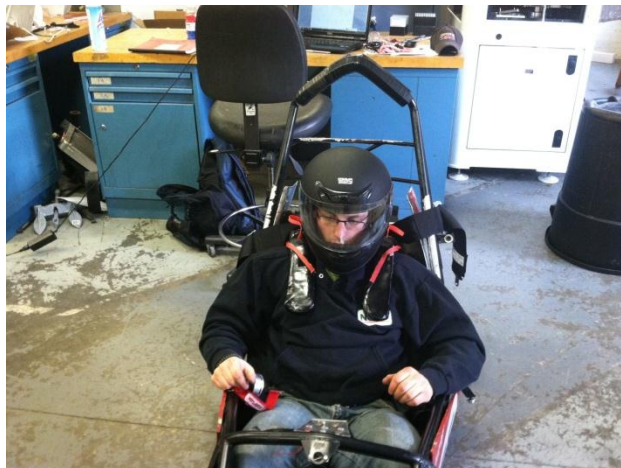


Figure 103. User Having Moved the Belts out of the Way

Step 3: Locate (Figure 104) and pull (Figure 105 and Figure 106) the tethers on the helmet, which release the quick releases from the helmet. A close-up view of a user pulling on the quick release tethers is displayed in Figure 107, while Figure 108 shows the quick release once it is opened.



Figure 104. User Locating the Tethers on the Helmet

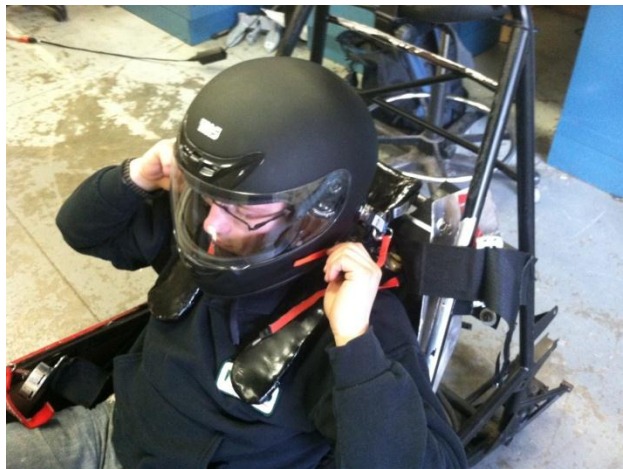


Figure 105. User Pulling the Tethers on the Helmet - Side View



Figure 106. User Pulling the Tethers on the Helmet - Front View



Figure 107. User Pulling on Quick Release Tethers

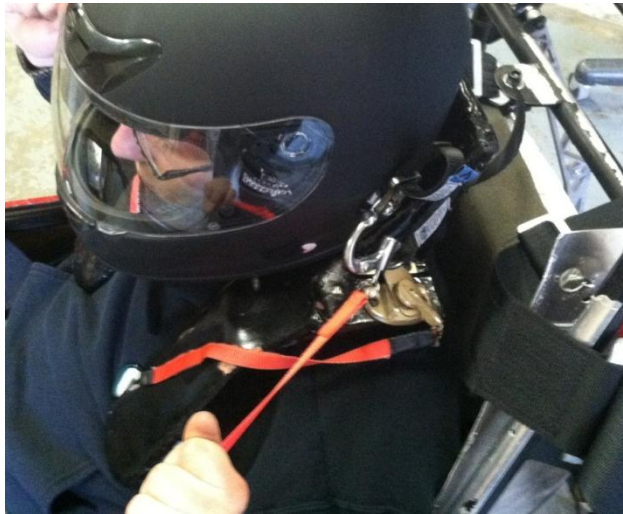


Figure 108. User with Opened Quick Releases

Step 4 (option #1): Locate and pull (Figure 109 and Figure 110) one of the tethers forward at approximately a 15° angle in relation to the wing while holding the opposite wing in one hand. This releases one wing from the device. Figure 111 shows the angle at which the tether should be pulled via the red arrows.



Figure 109. User Locating Wing Tether

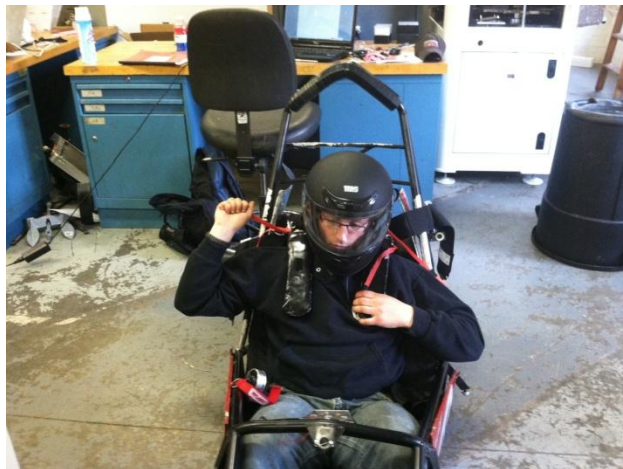


Figure 110. User Pulling Tether Forward at an Angle

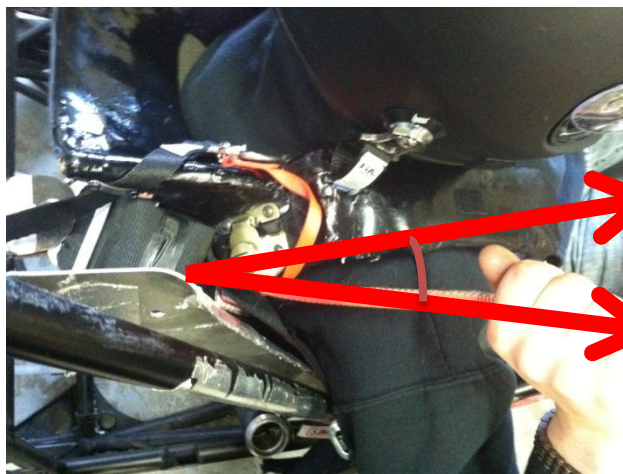


Figure 111. Close Up of the Angle at which the Tether Should be Pulled

Step 4 (option #2): Locate and pull (Figure 112 and Figure 113) both of the tethers forward at approximately a 15° angle in relation to the wing. This method releases both wings simultaneously.



Figure 112. User Locating Both Tethers on the Wings



Figure 113. User Pulling Both Tethers Simultaneously

Step 5: Remove the device into two or three pieces depending on the method of removal. This allows the user to exit the car without the device, but keeping the helmet on for protection.

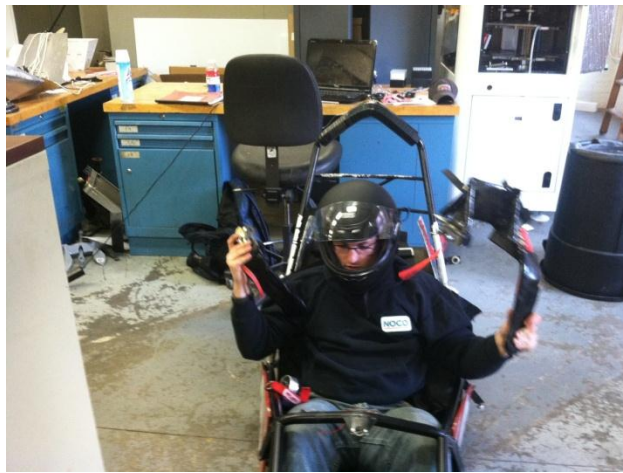


Figure 114. User Removing the Device into Two Pieces



Figure 115. User Removing the Device into Three Pieces

Appendix H – One-Tailed Matched Pair T-Test

A matched pair t-test was used to compare the time data collected from the tests. The null hypothesis was defined as the mean difference between the time to remove the device as a whole to mimic removing a HANS device and the time to remove the device by releasing a wing via a quick release latch was equal to zero. For easier comprehension, this equation was used calculate the difference, $D = \text{time for Test \#2} - \text{time for Test \#3}$, where Test #3 involved the usage of the quick release latch to remove the device. The alternative hypothesis was that the mean time difference was greater than zero signifying that it would take less time to remove the device via releasing the wing. Symbolically, the hypotheses are:

Null Hypothesis: $H_0: \mu_d = 0$ seconds

Alternative Hypothesis: $H_1: \mu_d > 0$ seconds.

A P-value of .05 was chosen as that is the typical value used to determine statistical significance. Considering that 11 participants were involved in testing, the degrees of freedom (DOF) was defined as 10, since $DOF = n - 1$, or one less than the total sample size.

Calculating the Mean Time Difference

$\mu_d = \frac{\sum \Delta T}{n}$, where ΔT is the time difference and n is the number of participants

$$\mu_d = \frac{.29 + 4 + 2.7 - .82 + 3.82 + .56 + 2 + 6 + 1.44 + 2.66 + .93}{11}$$

$$\mu_d = 2.143 \text{ seconds}$$

Calculating the Standard Deviation

$s = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$, where x is the time difference for each individual and \bar{x} is the mean time

difference for the sample population

Table 11. Time Difference Data used for Calculating the Standard Deviation

ID #	Time Difference	$x-\bar{x}$	$(x-\bar{x})^2$
1	0.29	-1.853	3.434
2	4	1.857	3.448
3	2.7	0.557	0.310
4	-0.82	-2.963	8.779
5	3.82	1.677	2.812
6	0.56	-1.583	2.506
7	2	-0.143	0.020
8	6	3.857	14.876
9	1.44	-0.703	0.494
10	2.66	0.517	0.267
11	0.93	-1.213	1.471

$$s = \sqrt{\frac{3.434 + 3.448 + .31 + 8.779 + 2.812 + 2.506 + .02 + 14.876 + .494 + .267 + 1.471}{10}}$$

$$s = 1.96 \text{ seconds}$$

Calculating the Test Statistic

$$T = \frac{\bar{x}}{\frac{s}{\sqrt{n-1}}}$$

$$T = \frac{2.143}{\frac{1.96}{\sqrt{11-1}}}$$

$$T = 3.457$$

Rejection Criteria

Given the type of t-test used and the hypothesis, the rejection criteria for this test was defined that if the test statistic was greater than the critical value ($T > T^*$) for the specified p-value and the degrees of freedom, the null hypothesis could be rejected for the alternative hypothesis.

Result

Using the T distribution Critical Values table, the critical value was determined to be 1.8124 using 10 as the DOF and the alpha value (or p-value) of .05 (Johnson, 1992). Since $3.457 > 1.8124$, the null hypothesis can be rejected for the alternative hypothesis, which proves that the time to remove the device by releasing a wing via the quick release latch is statistically less than the time to remove the device like a HANS device.

Appendix I – Economic Analysis

Given that this device would be a commercial product, a cost analysis is needed to determine the cost to manufacture the device in a larger volume setting and the future retail price for the device. As the cost of products that are mass-produced are affected by the number of items purchased and/or made each year, it is required that the initial number of products made be chosen before any calculations. With a relatively small market in comparison to other products, hundreds of people would probably purchase this head and neck restraint on a yearly basis. For the purpose of the project, the group estimated that 200 devices would be made in its first year of production. With that value known, the following steps of the economic analysis can then transpire.

Before the price for the device can be set, the total cost of the materials for each device needed to be calculated as it heavily affects the proposed price of the device when on the market. Starting with the skeletal portion of the device, the price of the aluminum bar stock needed to manufacture the device is strictly dependent on the length. Onlinemetals.com, the website from which the material was purchased, lists prices for the extruded aluminum bar rectangle 6061 starting with one foot of material and increases incrementally by the foot. The quantity of the material and the cost for the specific amount were entered in Excel to derive the equation relating the amount of the aluminum bar stock and its noted selling price. The data were plotted (Figure 116) and a linear regression fit was used to develop the appropriate equation to describe the given data.

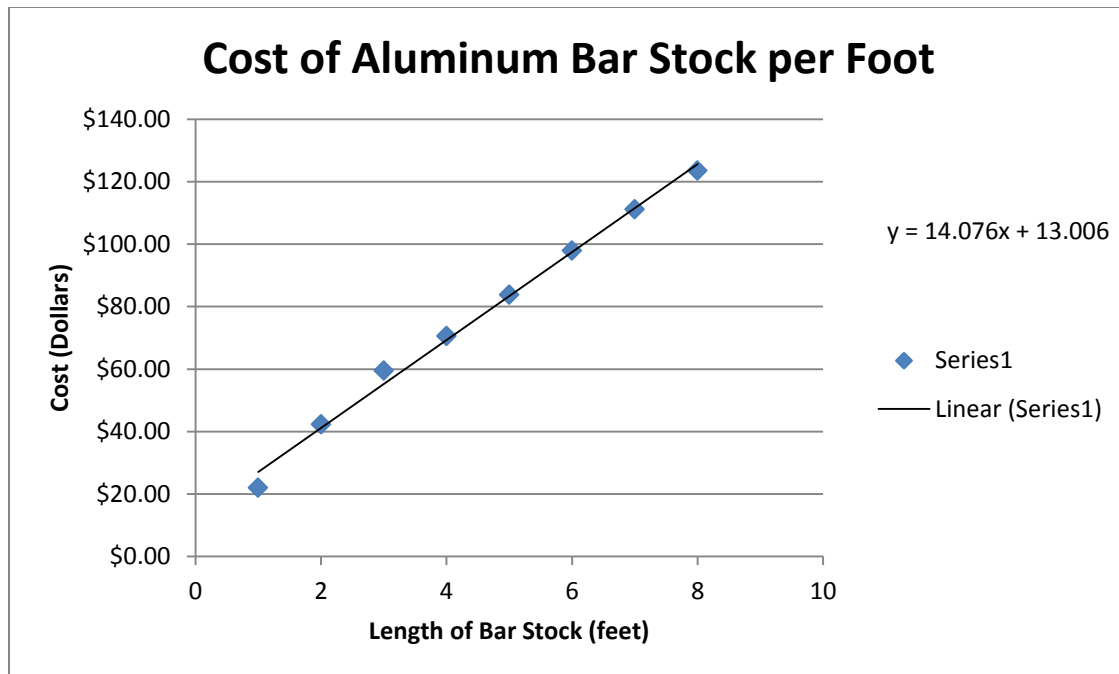


Figure 116. Plot of the Cost of Aluminum Bar Stock per Foot

The equation developed from the data was found to be, $y = 14.076x + 13.006$, where x is the amount of the material in feet and y is the cost in dollars. Since about one foot of stock is needed for one device, the value for x for this situation was equal to the number of devices made multiplied by the amount of bar stock per device ($x = 200 \text{ devices} * 1 \frac{\text{foot}}{\text{device}} = 200 \text{ ft}$). This makes the total cost of the aluminum bar stock to be \$2828.21, which is divided by the number of devices made to figure out the cost of the bar stock per device when buying in bulk. Therefore, the cost of the aluminum bar stock per device is \$14.14.

A similar procedure was completed to clarify the cost of the aluminum tubing per device. Using Onlinemetals.com once again, the data regarding the lengths of the tubing and the price for each specified length were plotted (Figure 117), and a regression line was fit to the data.

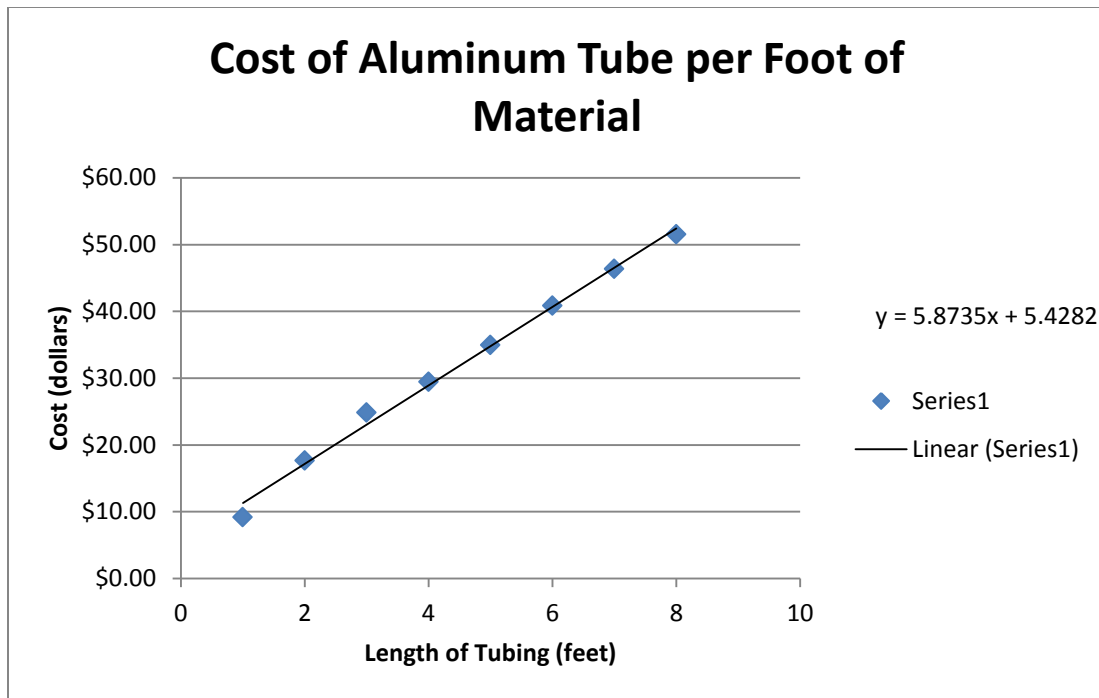


Figure 117. Plot of the Cost of the Aluminum Tubing by Foot of Material

The regression fit for this set of a data yielded the equation, $y = 5.8735x + 5.4282$, where y is equal to the cost of the material and x is the amount of aluminum tubing purchased. With approximately 6.5 feet of aluminum tubing required to make one device, the cost for the tubing to make 200 devices is about \$7640, making the cost of the tubing per device to be \$38.20 (Online Metal Store).

The other significant materials necessary to make the device were fiberglass, resin, hardener, and latches. According to Fiberglass Warehouse, 38 inches of fiberglass costs \$5.98; considering about .24 yards of fiberglass was used for one device, only \$1.45 is spent on the material per device (Fiberglass Products). For the resin, about 20 fluid ounces was used to coat one device. Since the resin purchased came with hardener, the cost for both items together is about \$7.29. The last significant material that needs to be incorporated into the cost analysis is the latches, which cost \$3.27 per latch; as two latches are featured on the device, the total cost for the latches for a single device is \$6.54. Having verified the price of each material per device, the

cost for all of the materials per device turned out to be \$67.62. Table 12 contains all of the information for the cost of each material per device.

Table 12. Cost of Materials per Device (Assuming 200 Devices are made)

Cost of Materials per Device	
Materials:	
Aluminum Bar Stock	\$14.14
Aluminum Tubing	\$38.20
Fiberglass	\$1.45
Resin/Hardener	\$7.29
Latches	\$6.54
<i>Total</i>	\$67.62

The next component that is involved in the analysis is the cost to manufacture the device based on the average hourly wage of a machinist, welder, and packaging expert. The yearly wages of each type of worker was determined using Salary Wizard, which was then used to calculate the workers' hourly wage. Table 13 contains the salaries of each type of worker by the year, week, and hour.

Table 13. Salaries of Workers Needed to Manufacture the Device by Year, Week, and Hour

Salaries			
	<i>Year</i>	<i>Week</i>	<i>Hour</i>
Welder	\$40,302	\$775.04	\$19.38
Machinist	\$35,015	\$673.37	\$16.83
Packaging	\$28,283	\$543.90	\$13.60

The amount of time that was spent machining and welding was estimated based on the manufacturing of the prototype. Additionally, the time to package a device was projected as well based on assumptions. The hourly wages and the amount of time spent on each activity were multiplied to see how much it costs to manufacture the entire device. Table 14 contains the number of hours spent performing each activity to form one device and the relative cost of doing so.

Table 14. Hours Spent on Each Activity and Cost of Labor per Device

Cost of Labor per Device		
<i>Labor</i>	<i>Hours</i>	<i>Cost</i>
Welding	8	\$155.01
Machining	3	\$50.50
Packaging	2	\$27.20
	<i>Total</i>	\$232.71

The final expense that has to be incorporated in the economic analysis is the overhead cost, which includes the indirect costs or fixed expenses of running a business. As these costs are typically established via a percentage of the cost of labor, it was decided that an additional 60% (of the labor costs) would be implemented into the total expenses; using this percentage, the overhead costs for each device amounts to \$139.62. With the material, labor, and overhead cost verified, the total cost to manufacture 200 devices is \$439.95. To set a retail price for the device, a mark-up value must be set to produce a profit. Examining existing head and neck restraints and other pieces of technology, the group decided that a mark-up value of 2.5 would be used for this project, which resulted in the retail price being about \$1100 if 200 devices were made. If the devices were to be sold at that price point, the gross income per device purchased would be about \$660 making the yearly gross income to be roughly \$132,000.